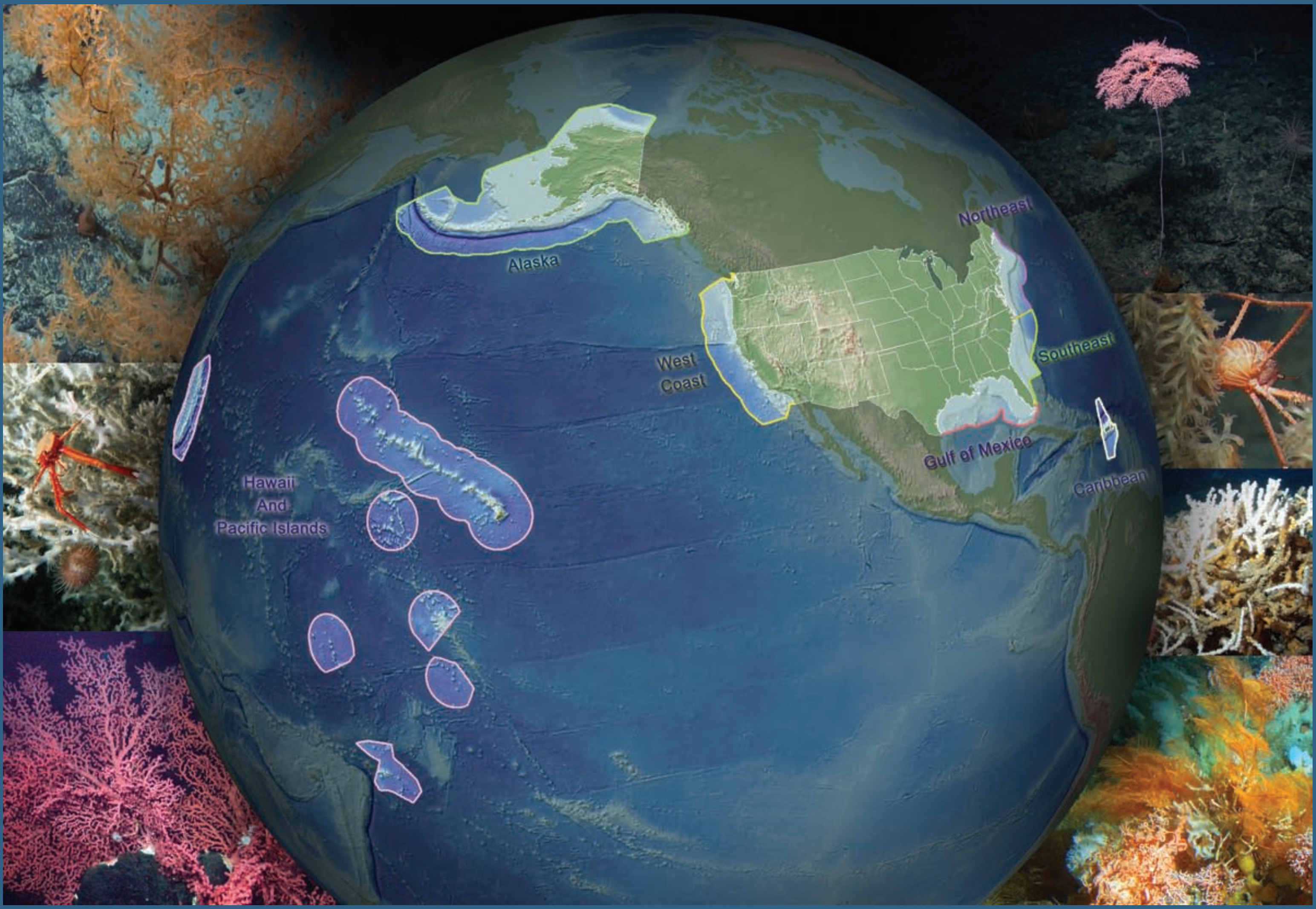

THE STATE OF DEEP CORAL ECOSYSTEMS OF THE UNITED STATES: 2007

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The State of Deep Coral Ecosystems of the United States

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National Oceanic and Atmospheric Administration

October 2007

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Overall Report and Chapter 1: Introduction and Overview

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Chapter 5: Northeast

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The State of the Deep Coral Ecosystems of the United States

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PREFACE

This report represents the first effort by the National Oceanic and Atmospheric Administration (NOAA), in partnership with other federal, academic and non-governmental partners, to bring together available information on the abundance and distribution of structure-forming corals that occur in U.S. waters at depths greater than 50 m. It consists of an introduction, National Overview and seven regional chapters describing deep coral communities in U.S. waters off Alaska, the U.S. West Coast, Hawai'i and the U.S. Insular Pacific, the Northeastern U.S., Southeastern U.S., Gulf of Mexico, and U.S. Caribbean. This report reflects the tremendous increase in awareness of these communities that has evolved over the last few years as the result of increasing exploration and research to understand deeper regions of the oceans. In the U.S., NOAA is proud to serve as a leading partner in much of this work.

NOAA coordinated the development of this report, under the auspices of the Deep Coral Team of the NOAA Coral Reef Conservation Program. It reflects the work and dedication of writing teams from each region and these teams should be cited as primary authors of the regional chapters. The report also benefited from the comments and suggestions of numerous federal and external reviewers and a Data Quality Act peer review coordinated through the Center for Independent Experts.

An introductory chapter defines and provides background information on structure-forming deep corals and identifies major threats that they face. A National Overview explores general trends in these communities across the regions from a national perspective. Chapters 2 through 8, the regional chapters, were developed by authors considered experts in the field of deep coral research and management and those chapters represent the core of this report. The authors of each chapter briefly describe the region and geological and oceanographic features important to deep coral communities; identify the major deep coral taxa that structure habitats in the region and what is known about their distribution; provide information on the other species associated with coral habitat; describe the threats to these habitats; discuss management efforts developed to respond to these threats, and briefly outline regional information needs.. The report also includes unpublished data and observations collected during recent research expeditions.

This report fulfills a commitment made in the U.S. Ocean Action Plan as part of an overall effort to research, survey and protect deep coral communities. It reflects NOAA's growing understanding of the importance of these communities as hot-spots for deep-water biological diversity, and NOAA's commitment to ensuring their enhanced conservation. This report is also a central part of a broader NOAA effort to develop a National Deep Coral and Sponge Research, Conservation and Management Strategy. We hope that this first *Report on the State of Deep Coral Ecosystems of the United States* will stimulate additional research, surveys and protection, and hope that periodic future reports will document both increased understanding and protection of these unique and valuable ecosystems.

STATE OF DEEP CORAL ECOSYSTEMS OF THE UNITED STATES: INTRODUCTION AND NATIONAL OVERVIEW

Thomas F. Hourigan[1], S. Elizabeth Lumsden[1], Gabrielle Dorr[2], Andrew W. Bruckner[1],
Sandra Brooke[3], Robert P. Stone[4]

INTRODUCTION

Coral reefs are among the most spectacular ecosystems on the planet, supporting such rich biodiversity and high density of marine life that they have been referred to as the "rainforests of the sea." These ecosystems are usually associated with warm shallow tropical seas, generally within recreational diving depths (30 m or less). However other coral communities thrive on continental shelves and slopes around the world, sometimes thousands of meters below the ocean's surface. These communities are structured by deep corals, also referred to as "deep-sea corals" or "cold-water corals," and are found in all the world's oceans. Unlike the well-studied shallow-water tropical corals, these corals inhabit deeper waters on continental shelves, slopes, canyons, and seamounts in waters ranging from 50 m to over 3,000 m in depth. A few species also extend into shallower, cold waters in the northern latitudes (Figure 1.1).

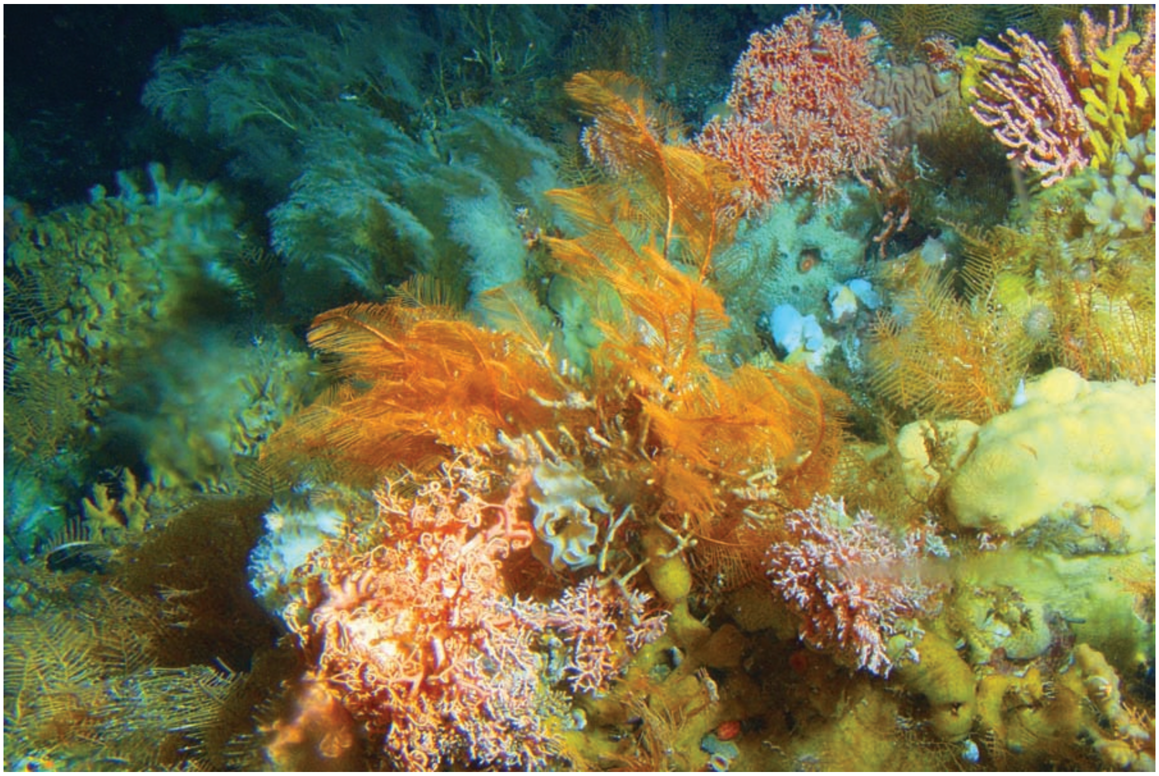

Figure 1.1 An Alaskan "coral garden" with several species of soft corals, hydrocorals, hydroids, and demosponges. Photo credit: Alberto Lindner

Deep coral habitats appear to be much more extensive and important than previously known, particularly with respect to supporting biologically diverse faunal assemblages (Wilkinson 2004; Roberts et al. 2006). At the same time, they are

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increasingly threatened by a variety of activities ranging from bottom fishing to energy exploration (Rogers 1999; Koslow et al. 2000). Over the past decade, science has demonstrated that deep corals are often extremely long-lived, slow-growing animals, characteristics that make them particularly vulnerable to physical disturbance, especially from activities such as bottom trawling. Where water, current, and substrate conditions are suitable, these corals can form highly complex reef-like structures, thickets or groves, and there is increasing evidence that many areas of deep coral and sponge habitats function as ecologically important habitats for fish and invertebrates.

black corals, and gorgonians among the more prominent deep coral groups, while the Class Hydrozoa contains the stylasterid corals (often referred to as lace corals) in the order Anthoathecatae. As a group, deep corals are among the most incompletely understood corals, and field and laboratory investigations are sparse.

Deep corals in this report are distinguished from “shallow” tropical corals, the subject of a separate NOAA status report (Waddell 2005), by restricting consideration to azooxanthellate corals, meaning they lack the symbiotic algae (zooxanthellae) found in most shallow corals and do not require sunlight to grow. The depth range defining “deep” corals for the purposes of this report (>50 m), while somewhat arbitrary, is based on the best scientific information available (e.g., depths at which azooxanthellate corals predominate over zooxanthellate corals) as well as by practical conservation considerations. Generally, “deep-sea organisms” are defined as those occurring deeper than the continental shelf (generally around 200 m). However, a number of coral communities of management interest occur at shallower depths (e.g., *Oculina* coral banks off Florida and black coral beds in Hawaii), and share functional similarities to true deep-sea coral taxa. Even though several of these coral species have been harvested for jewelry since antiquity, and their existence has been known to science since 1758 (when Carl von Linné wrote

Box 1.1 “Structure-forming deep corals” and “deep coral communities” defined:

For the purposes of this report:

Structure-forming deep corals are any colonial, azooxanthellate corals generally occurring at depths below 50 m that provide vertical structure above the seafloor that can be utilized by other species. It includes both branching stony corals that form a structural framework (e.g., reefs) as well as individual branching coral colonies, such as gorgonians and other octocorals, black corals, gold corals, and lace corals. Though these are often referred to as habitat-forming deep-sea, deep-water, or cold-water corals, the more neutral term “structure-forming” has been used in this document to avoid an implication of habitat associations with other species until such associations have been demonstrated by the best available science. Tables of important structure-forming coral species within the U.S. EEZ are listed in Appendix 1.1 and 1.2.

Deep coral communities are defined as assemblages of structure-forming deep corals and other associated species, such as sedentary and motile invertebrates and demersal fishes.

WHAT ARE STRUCTURE-FORMING DEEP CORALS?

Structure-forming deep corals, as used in this report (Box 1.1), include a number of very different species that contribute to three-dimensionally complex habitats in deeper waters. Structure-forming deep corals are defined as those coral species with complex branching morphology and sufficient size to provide substrate or refuge for associated fishes and invertebrates. As such, they represent a functional group of conservation interest, rather than a taxonomic group, which Morgan et al. (2006) have likened to the diverse plants included under the descriptors “bushes” or “trees.” These coral species are found within two cnidarian Classes, Anthozoa and Hydrozoa (Box 1.2). Anthozoa includes the stony corals,

Box 1.2. Taxonomy of Major Coral Groups[1]

"Coral" is a general term used to describe several different groups of animals in the Phylum Cnidaria. The following is a summary of cnidarian taxonomy as used in this report, showing the primary groups containing animals referred to as "corals." Orders in **bold** contain structure-forming deep corals.

PHYLUM CNIDARIA

- I. Class Anthozoa - corals, sea anemones, sea pens
  - I.A. Subclass Hexacorallia (Zoantharia) - sea anemones, stony and black corals
    - I.A.1. **Order Scleractinia - stony corals (The most important families containing deep-water structure-forming stony corals are Carophylliidae, Dendrophylliidae, and Oculinidae)**
    - I.A.2. **Order Zoanthidea - zoanthids (family Gerardiidae**)
    - I.A.3. **Order Antipatharia[2] - black corals**
  - I.B. Subclass Octocorallia (Alcyonaria) – octocorals
    - I.B.1 **Order Alcyonacea - true soft corals, stoloniferans[3]**
    - I.B.2 **Order Gorgonacea[4] - sea fans, sea whips (there are at least 12 families containing deep-water structure-forming gorgonians)**
    - I.B.3 **Order Pennatulacea - sea pens**
    - I.B.4 **Order Helioporacea - Lithotelestids** and blue corals
- II. Class Hydrozoa - hydroids and hydromedusae
  - II.A.1. **Order Anthoathecatae[5] - stylasterid corals** and fire corals
    suborder Filifera (Stylasteridae: stylasterids, lace corals)
- III. Class Cubozoa - does not contain corals
- IV. Class Scyphozoa - does not contain corals

[1] Taxonomic summary generally follows that presented in the Integrated Taxonomic Information System (**http://www.itis.gov**).

[2] Black corals were formerly placed in the subclass Ceriantipatharia; however, based on recent molecular data they are now considered to be in the same subclass as other hexacorals.

[3] Current taxonomy has the order Stolonifera combined with Alcyonacea (S. Cairns pers. comm.)

[4] Not all taxonomists recognize the order Gorgonacea as separate from Alcyonacea.

[5] The order containing lace corals (family Stylasteridae) was previously called Filifera or Stylasterina. Filifera is now considered a suborder and Stylasterina is no longer valid (S. Cairns pers. comm.).

the Systema Natura) relatively little is known about their biology, population status, the role they play in enhancing local species diversity, or their importance as habitat for deep-water fishes, including those targeted by fishermen. With recent advances in deep-sea technology, scientists are now beginning to locate and map the distribution of deep coral habitat, and the past 15 years has seen a rapid expansion of studies on these deep-sea communities worldwide.

Deep corals include both reef-building and non-reef-building corals. Although only a few stony coral species (order Scleractinia) form deep-water structures such as bioherms, coral banks or lithoherms (Box 1.3) (Freiwald et al. 2004; George 2004a, b; Cairns in press), these species can occur as individual small colonies less than a meter in diameter or they may form aggregations that can create vast reef complexes tens of kilometers across and tens of meters in height over time (Freiwald et al. 2004; Roberts et al. 2006).

Shallow corals need well-known and well-documented environmental conditions for development; however the requirements for deep coral species are not as well understood. Table 1.1 highlights some of the general differences and similarities between shallow and deep stony corals. The major structure-forming coral taxa are described in a later section. Unlike stony

Box 1.3 Geological Terms (see Chapter 8 for more detail)

Bioherm - A moundlike or reeflike formation built by organisms such as corals, algae, foraminfera, mollusks, etc., composed almost exclusively of their calcareous remains and trapped sediments, and surrounded by rock of different physical characteristics. It may take the form of an unconsolidated coral mound or reef, or be covered by crust-like layers of limestone (Lithoherm).

Coral bank - An undersea mound or ridge that rises above the surrounding continental shelf or slope and is formed in part from the carbonate skeletons of corals.

Lithoherm - A deep-water mound of limestone, usually formed by submarine consolidation of carbonate mud, sand and skeletal debris

Table 1.1 Differences between tropical shallow-water and deep-water structure-forming stony corals

Parameter	Tropical shallow stony corals[1]	Deep stony corals[1]
Depth range	0-100 m	39-3,000 m
Temperature	18-31º C	4-13º C
Distribution	Tropical and subtropical seas from 30ºN-30ºS	Potentially global, at least 56º S-71º N
Symbiotic Algae	Yes	No (Note: several species of *Oculina* and *Madracis* have a facultative relationship with zooxanthellae in shallow populations)
Growth rates	1-10 mm per year for massive slow growing corals	1-20 mm per year for *Oculina* and *Lophelia*[3]; growth rates of other taxa are unknown.
	50-150 mm per year for faster growing branching corals	
Number of reef building species	Approximately 800	Approximately 6-14
Nutrition	Photosynthesis, zooplankton and suspended organic matter	Zooplankton and possibly suspended organic matter
Primary Threats[1,2]	Overfishing and destructive fishing	Bottom-tending fishing gear
	Pollution and siltation	Oil and gas exploration and production
	Coastal development	Pipelines and cables
	Harvest of corals	Climate change (ocean acidification and possible changes in currents and temperatures)
	Recreational misuse	
	Diseases	
	Climate change (coral bleaching, ocean acidification and storm intensity)	

1. Modified from Freiwald et al. 2004
2. U.S. Coral Reef Task Force 2000 - Threats to shallow coral reefs
3. Mortensen and Rapp (1998) reported rates of 25 mm/yr but this is thought to be an overestimate due to the sampling methodology.

corals, other deep coral taxa, such as stylasterids, gorgonians, and black corals do not form reefs, but often have complex, branching morphologies and may form dense groves or thickets. Sea fans may exist either singly on the seafloor or within large and complex ecosystems. The North Pacific, for example, is known to have extensive coral "gardens" composed of gorgonians and numerous other coral and sponge species.

WHY ARE DEEP CORAL ECOSYSTEMS IMPORTANT?

As the understanding of deep coral communities and ecosystems has increased, so has appreciation of their value. Deep coral communities can be hot-spots of biodiversity in the deeper ocean, making them of particular conservation interest. Stony coral "reefs" as well as thickets of gorgonian corals, black corals, and hydrocorals are often associated with a large number of other species. Through quantitative surveys of the macroinvertebrate fauna, Reed (2002b) found over 20,000 individual invertebrates from more than 300 species living among the branches of ivory tree coral (*Oculina varicosa*) off the coast of Florida. Over 1,300 species of invertebrates have been recorded in an ongoing census of numerous *Lophelia* reefs in the northeast Atlantic (Freiwald et al. 2004), and Mortensen and Fosså (2006) reported 361 species in 24 samples from *Lophelia* reefs off Norway. Gorgonian corals in the northwest Atlantic have been shown to host more than 100 species of invertebrates (Buhl-Mortensen and Mortensen 2005). An investigation by Richer de Forges et al. (2000) reported over 850 macro- and megafaunal species associated with seamounts in the Tasman and south Coral Seas with many of these species associated with the deep coral *Solenosmilia variabilis* (Rogers 2004). The three-dimensional structure of deep corals may function in very similar ways to their tropical counterparts, providing enhanced feeding opportunities for aggregating species, a hiding place from predators, a nursery area for juveniles, fish spawning aggregation sites, and attachment substrate for sedentary invertebrates (Fosså et al. 2002; Mortensen 2000; Reed 2002b).

The high biodiversity associated with deep coral communities is intrinsically valuable, and may provide numerous targets for chemical and biological research on marine organisms. For example, several deep-water sponges have been shown to contain bioactive compounds of pharmaceutical interest; sponges are often associated with deep coral communities. Bamboo corals (family Isididae) are being investigated for their medical potential as bone grafts and for the properties of their collagen-like gorgonin (Ehrlich et al. 2006). A number of deep corals are also of commercial importance, especially black corals (order Antipatharia) and pink and red corals (*Corallium* spp.), which are the basis of a large jewelry industry. Black coral is Hawaii's "State Gem."

Deep coral communities have also been identified as habitat for certain commercially-important fishes. For example, commercially valuable species of rockfish, shrimp, and crabs are known to use coral branches for suspension feeding or protection from predators in Alaskan waters (Krieger and Wing 2002). Husebø et al. (2002) documented a higher abundance and larger size of commercially valuable redfish, ling, and tusk in Norwegian waters in coral habitats compared to non-coral habitats. Costello et al. (2005), working at several sites in the Northeast Atlantic, report that 92% of fish species, and 80% of individual fish were associated with *Lophelia* reef habitats rather than on the surrounding seabed. Koenig (2001) found a relationship between the abundance of economically valuable fish (e.g., grouper, snapper, sea bass, and amberjack) and the condition (dead, sparse and intact) of *Oculina* colonies. *Oculina* reefs off Florida have been identified as essential fish habitat for federally-managed species, as have gorgonian-dominated deep coral communities off Alaska and the West Coast of the United States. In other cases, however, the linkages between commercial fisheries species and deep corals remain unclear (Auster 2005; Tissot et al. 2006) and may be indirect.

Due to their worldwide distribution and the fact that some gorgonian and stony coral species can live for centuries, deep corals may serve as a proxy for reconstructing past changes in global climate and oceanographic conditions (Risk et al. 2002; Williams et al. 2007). The calcium carbonate skeletons of corals incorporate trace elements and isotopes that reflect the physical and chemical conditions in which they grew. Analysis of the coral's microchemistry has allowed researchers to reconstruct past oceanic conditions.

MAJOR GROUPS OF STRUCTURE-FORMING DEEP CORALS

The term “coral” is broadly used to describe a polyphyletic assemblage of several different groups of animals in the phylum Cnidaria and includes a range of taxa (Box 1.2). Structure-forming corals outlined in this document are animals in the cnidarian Classes Anthozoa and Hydrozoa that produce calcium carbonate (aragonite or calcite) secretions. These secretions have different forms: a continuous skeleton, numerous, usually microscopic, individual sclerites, or a black, horn-like, proteinaceous axis (Cairns in press). The following are the major classes and orders that include important structure-forming deep corals. Species identified in this report as important structure-forming corals in U.S. waters are shown in Appendix 1.1 and 1.2.

PHYLUM CNIDARIA

I. CLASS ANTHOZOA

Anthozoa, the largest Class of cnidarians, contains over 6,000 described species (Barnes 1987). They are found as both solitary and colonial arrangements. They have a cylindrical body shape with an oral opening surrounded by tentacles, and have lost the medusoid (medusa or jellyfish shape) life history stage. In anthozoans, the mouth leads through the pharynx to the gastrovascular cavity, a feature unique to cnidarians that serves both a digestive and a circulatory function. This cavity is divided into compartments radiating outward from the pharynx and is lined with nematocysts.

I.A. SUBCLASS HEXACORALLIA

I.A.1. ORDER SCLERACTINIA (STONY CORALS)

Stony corals (order Scleractinia) are exclusively marine anthozoans with over 1,400 described species. Individual polyps secrete a rigid external skeleton composed of calcium carbonate in the crystal form aragonite. Over 776 of the recognized stony corals are found in shallow water and contain zooxanthellae (symbiotic algae) that provide much of the coral’s nutrition, while deep-water species lack zooxanthellae. While more than 90% of the shallow stony corals are colonial structure-forming species (many contributing to coral reefs), there are at most 14 species of azooxanthellate deep-water scleractinians in the world that can be considered structure-forming species, 13 of which occur in U.S. waters (Cairns 2001; Cairns in press). The other 97.7% of the deep-water species are for the most part small (some as small as 2 mm adult size) and solitary (74%) (Cairns 2001). Two deep corals that are major contributors to reef-like structures or bioherms in U.S. waters (*Lophelia pertusa,* and *Oculina varicosa)* while other stony corals including *Madrepora oculata, Solenosmilia variabilis,* and *Enallopsammia profunda* contribute to the formation of bioherms and reefs in some areas. *Goniocorella dumosa* (Alcock 1902) is an important framework-building coral found in the southwest Pacific Ocean, especially around New Zealand, where it can form large, localized reefs up to 40 m in height and 700 m wide. *G. dumosa* appears to be restricted to the southern hemisphere, and has not been reported from U.S. waters (Cairns 1995).

I.A.1.A. FAMILY CARYOPHYLLIIDAE

I.A.1.a.i. *Lophelia pertusa* (Linnaeus,1758)[1]

Description: *Lophelia pertusa* belongs to the family Caryophylliidae, Vaughan and Wells, 1943. At present the genus *Lophelia* is monotypic (Zibrowius 1980). A number of different *Lophelia* species were described previously, but were either synonymous with *L. pertusa* or reclassified into other genera (for a list of synonyms see Rogers 1999). Worldwide, *L. pertusa* is the most important constituent of deep-water coral reefs, forming massive complexes hundreds of kilometers long and up to 30 m high (Freiwald et al. 2004). *L. pertusa* is often found in association with *E. profunda*, *M. oculata,* and *S. variabilis* in

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[1] Note on nomenclature: The name of the author who described the species follows the species name, e.g., *Solenosmilia variabilis* Duncan, 1873. If subsequent work has placed a species in a different genus, the author’s name appears in parentheses, e.g., *Enallopsammia profunda* (Pourtalès, 1867).

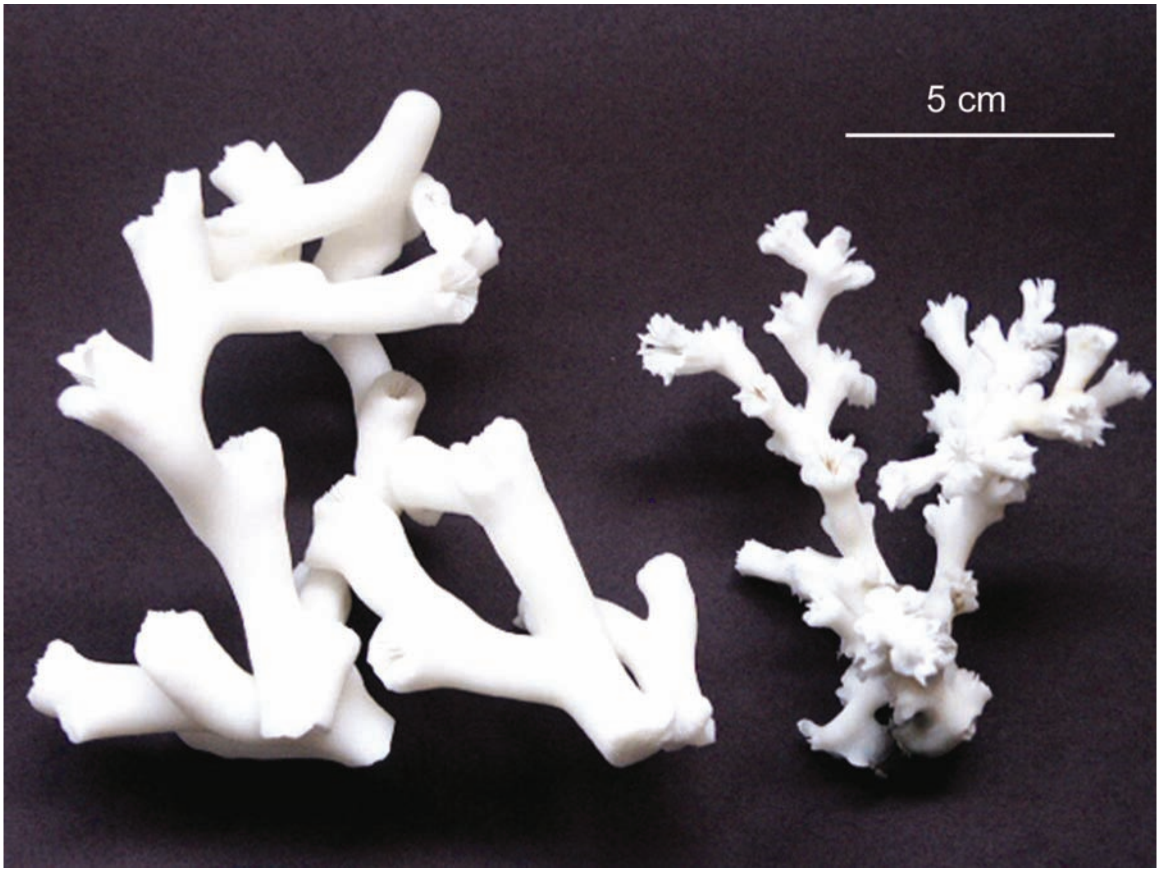

Figure 1.2 Samples of *Lopehlia pertusa* colonies collected from the Gulf of Mexico. The left specimen displays the more heavily calcified "brachycephala" morphology with large polyps, and the right specimen shows the more fragile "gracilis" morphology. Photo credit: Sandra Brooke, OIMB, Charleston, OR.

the western Atlantic, along the Blake Plateau, and along the Florida-Hatteras slope (Reed 2002b). *Lophelia* is fragile, slow growing, and extremely susceptible to physical destruction from fishery impacts (Fosså et al. 2002; Reed 2002b).

Distribution: *L. pertusa* is a widespread structure-forming deep-water scleractinian species occurring in the Atlantic, Pacific, Indian, and Southern Oceans, with a latitudinal range from about 56º S to 71º N (Freiwald et al. 2004). In U.S. waters major reefs have been reported off the southeastern U.S. (Chapter 6) and the Gulf of Mexico (Chapter 7). The species has also been reported from the West Coast (Chapter 3), the Caribbean (Chapter 8) and the New England Seamounts (Chapter 5).

Depth Range: *L. pertusa* has been recorded from depths as shallow as 39 m in the Norwegian fjords (Freiwald et al. 2004) and as deep as 2,170 m (Cairns 1979), but most commonly forms reefs at depths between 200 m and 1,000 m (Freiwald et al. 2004).

Morphology: This species displays great phenotypic plasticity in colony morphology ranging from heavily calcified structures with large polyps (1-1.5 cm in diameter) termed "brachycephala" by earlier workers, to the more delicate "gracilis" morphology with smaller polyps and more defined septal ridges (Figure 1.2; Newton et al. 1987). *Lophelia* colonies can exhibit great morphological variation, which may reflect the local environmental conditions of their habitat, but characteristically form bushy thicket-like structures composed of living branches overlying a center of dead coral (Figure 1.3). Branches are dendritic and readily fuse together, which increases colony strength.

Growth and Age: The growth rate of *L. pertusa* in the northeast Atlantic has been estimated at 5-26 mm yr^{-1} (Mortensen and Rapp 1998; Mortensen 2001; Gass and Roberts 2006), suggesting that large colonies probably represent hundreds of years of accretion. Radioisotope dating of *Lophelia* reefs from seamounts off northwest Africa, the Mid-Atlantic Ridge, and the Mediterranean suggest that they may have

Figure 1.3 Colonies of living and dead *Lophelia* with squat lobster. Photo credit: Ross et al., NOAA-OE.

grown continuously for the last 50,000 years (Schroder-Ritzrau et al. 2005).

Reproduction: *L. pertusa* is a gonochoristic species (separate sexes) that produces a single cohort of about 3,000 relatively small (max = 140 µm in diameter) oocytes per polyp each year (Waller and Tyler 2005). The species is an annual broadcast spawner, releasing gametes between January and February (Le Goff-Vitry and Rogers 2005; Waller and Tyler 2005). The low genetic diversity in some locations, the occurrence of genetically distinct fjord and offshore populations, and the presence of lecithotrophic larvae suggest there is a high degree of local recruitment (Le Goff-Vitry and Rogers 2005). Local recruitment, together with predominance of asexual reproduction via fragmentation, is thought to be critical in the persistence of populations, especially in areas impacted by trawling (Le Goff-Vitry and Rogers 2005; Waller and Tyler 2005).

Figure 1.4 *Solenosmilia variabilis* coral. Photo credit: Brooke et al., NOAA-OE, HBOI.

I.A.1.a.ii. *Solenosmilia variabilis* Duncan, 1873

Description: *Solenosmilia variabilis* (Figure 1.4) is a branching coral that often occurs as a secondary constituent of deep-water reefs. It is a prominent reef-building species on South Pacific seamounts.

Distribution: *S. variabilis* occurs throughout much of the Atlantic and Indo-Pacific Oceans, but is not found in the Arctic, Antarctic, and North and eastern Pacific waters (Cairns 1979). This coral forms dense clusters on Tasmanian

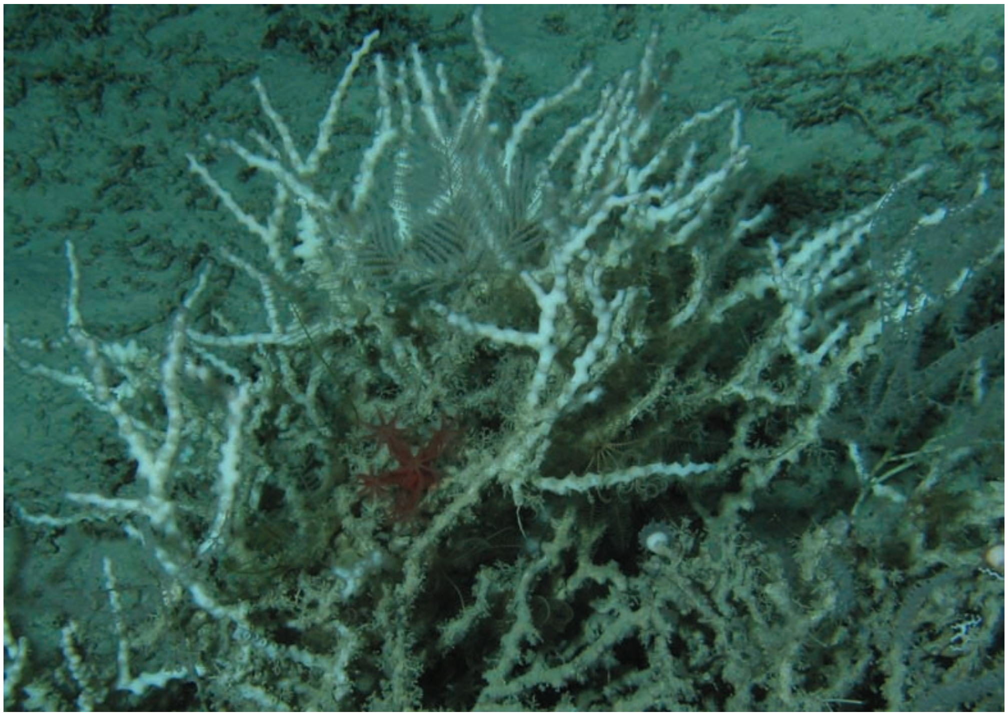

Figure 1.5 The deep coral *Enallopsammia profunda*. Photo credit: Brooke et al., NOAA-OE, HBOI.

Seamounts, along the Heezen Fracture Zone in the South Pacific, on Little Bahama Bank, and south of Iceland (Cairns 1979; Freiwald et al. 2004). *S. variabilis* is also associated with *L. pertusa*, *Madrepora* spp., and *E. profunda* in the western Atlantic on the Blake Plateau and along the Florida-Hatteras slope (Chapters 7 and 8).

Depth Range: *S. variabilis* is found at depths of 220-2,165 m, but is only known to occur at depths shallower than 1,383 m in the western Atlantic (Cairns 1979).

Morphology: *S. variabilis* forms bushy, tightly branched colonies.

Growth and Age: Limited information is available.

Reproduction: *S. variabilis* is a gonochoristic species with relatively small polyps (3.3 mm), small oocytes (148 µm), and low polyp fecundity (290) that increases with polyp size. The species is thought to be a broadcast spawner with annual reproduction in late April or May in New Zealand (Burgess and Babcock 2005).

I.A.1.B. FAMILY DENDROPHYLLIIDAE

I.A.1.b.i. *Enallopsammia profunda* (Pourtalès, 1867)

Description: *Enallopsammia profunda* is a major structure-forming species (Cairns 1979; Rogers 1999). It is often associated with *L. pertusa*, *M. oculata*, and *S. variabilis* (Reed 2002a; Reed et al. 2006).

Distribution: *E. profunda* is endemic to the western Atlantic and can be found from the Caribbean to Massachusetts. *E. profunda* can contribute significantly to the structure of deep-water coral banks found at depths of 600-800 m in the Straits of Florida (Cairns and Stanley 1982; Reed 2002a). For example, a site on the outer eastern edge of the Blake Plateau at depths of 640-869 m contains over 200 coral mounds where *E. profunda* is the dominant scleractinian coral (Stetson et al. 1962; Uchupi 1968; Reed 2002a). *Enallopsammia-Lophelia* reefs have a reported maximum vertical relief of 146 m (Reed 2002a; Reed et al. 2006).

Depth Range: *E. profunda* occurs at depths from 403-1,748 m (Cairns 1979).

Morphology: This species forms large branching

Figure 1.6 Specimen of *Enallopsammia rostrata* (31.4 cm) collected at 1,097 m off Bermuda. Specimen includes *L. pertusa* and *D. dianthus.* Photo credit: S. Lutz.

colonies up to 1 m in diameter (Cairns 1979; Freiwald et al. 2004) (Figure 1.5).

Growth, Age, and Reproduction: Limited information is available.

I.A.1.b.ii. *Enallopsammia rostrata*
(Pourtalès, 1878)

Description: *Enallopsammia rostrata* (Figure 1.6) is a widespread scleractinian species that is known to contribute to the structure of deep coral reefs. It is reported to form bioherms along the edges of oceanic banks, such as the Chatham Rise off New Zealand (Probert et al. 1997). It is considered a major structure-forming coral in Hawaii (Chapter 4) and the Caribbean (Chapter 8).

Distribution: *E. rostrata* has been reported from eastern and western Atlantic, the Indian Ocean, and numerous locations in the central and western Pacific (Cairns et al. 1999), ranging in latitude from 53° N (in the Atlantic) to 51° S in the Pacific. In U.S. waters it is the most important deep-water scleractinian in Hawaii, where it is common primarily at depths of 500-600 m (Chapter 4). In U.S. waters of the Atlantic, it has been reported to occur off Georgia (Chapter 6), Navassa Island and the U.S. Virgin Islands (Chapter 8).

Depth Range: *E. rostrata* occurs at depths from 215-2,165 m (Cairns 1979, 1984). In Hawaii, it is most common at depths of 500-600 m (Chapter 4). It occurs from 300-1,646 m in the western Atlantic (Chapter 8; Cairns 1979).

Figure 1.7 *Madrepora carolina* specimen (27.6 cm) collected at 333-375 m in the northwest Providence Channel off Grand Bahama Island. Photo credit: S. Lutz.

Morphology: *E. rostrata* forms tightly-branched, bushy colonies (Cairns 1979).

Growth and Age: Adkins et al (2004) reported that a single colony of *E. rostrata* from the North Atlantic was over 100 years old, with an estimated linear growth rate of 5 mm per year.

Reproduction: Burgess and Babcock (2005) reported that *E. rostrata* appeared to be a gonochoristic, broadcast spawner, although brooded larvae could not be ruled out. Maximum oocytes diameter was 400 μm with an average of 144 oocytes per polyp.

I.A.1.C. FAMILY OCULINIDAE

I.A.1.c.i. *Madrepora carolina*
(Pourtalès, 1871)

Description: *Madrepora carolina* has been reported on deep-water reefs, often in association with *E. profunda*, and other species, but it is not known to form the structural framework of these reefs (Freiwald et al. 2004).

Distribution: *M. carolina* occurs throughout the tropical western Atlantic in the Gulf of Mexico and off the southeastern United States, often co-existing with *M. oculata.*

Depth Range: *M. carolina* occurs from 53-1,003 m, but is most common between 200-300 m (Chapter 7; Cairns 1979; Dawson 2002).

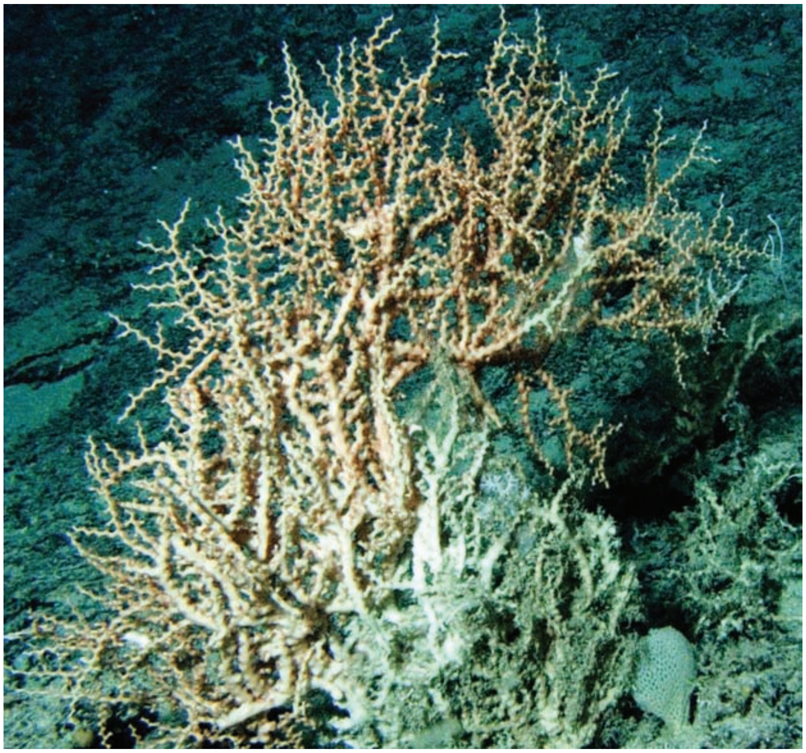

Figure 1.8a *Madrepora oculata* coral *in situ,* one of the three dominant corals that make up the deepwater reefs off Florida. Photo credit: Brooke et al, NOAA-OE, HBOI.

Figure 1.8b *Madrepora oculata* sample collected at the *Lophelia* coral banks off the coast of South Carolina. Photo Credit: Ross et al. and NOAA-OE.

Morphology: This species forms bush-like colonies with a thick base up to 28 mm in diameter (Cairns 1979; Figure 1.7).

Growth, Age, and Reproduction: Limited information is available.

I.A.1.c.ii. *Madrepora oculata* Linnaeus, 1758

Description: *Madrepora oculata* is not known to build reefs, but it is typically a secondary framework builder that occurs among colonies of *L. pertusa* off New Zealand, the Aegean Sea, and northeast Atlantic (Frederiksen et al. 1992; Freiwald et al. 2004; Waller and Tyler 2005*),* among *L. pertusa, E. profunda*, and *S. variabilis* off the southeast Atlantic (Reed 2002a; Reed et al. 2006) and *G. dumosa* off New Zealand (Cairns 1995). Recent molecular studies of the scleractinians have given a new insight into the evolutionary history of this group. Analysis of mitochondrial 16S rDNA suggests that *M. oculata* may have been misclassified, and it may actually form a monotypic clade between the families Pocilloporidae and Caryophylliidae (Le Goff-Vitry et al. 2004).

Distribution: *M. oculata* is one of the most widespread deep-water coral taxa. It has been recorded in temperate and tropical oceans around the world, extending from 69° N off Norway to 59° S latitude in the Drake Passage. Large individual colonies of *M. oculata* occur on exposed hard substrate throughout the Gulf of Mexico.

Depth Range: This species is known to occur from 55-1,950 m (Zibrowius 1980; Cairns 1982).

Morphology: *M. oculata* has a complicated skeletal morphology. It has extremely variable morphology, forming large bushy or flabellate colonies with a massive base that can be several centimeters in diameter (Cairns 1979). Colony branches have very distinctive “zig-zag” morphology (sympodial branching; Figures 1.8a and 1.8b). *M. oculata* is reported to be more fragile than *L. pertusa*, limiting its structure-building capability.

Growth and Age: Limited information is available.

Reproduction: The reproductive ecology of *M. oculata* contrasts sharply with that observed in *Lophelia*. While both are gonochoristic broadcast spawning species, *M. oculata* is thought to produce two cohorts per year and the oocytes are more than 2.5 times larger than *L. pertusa*

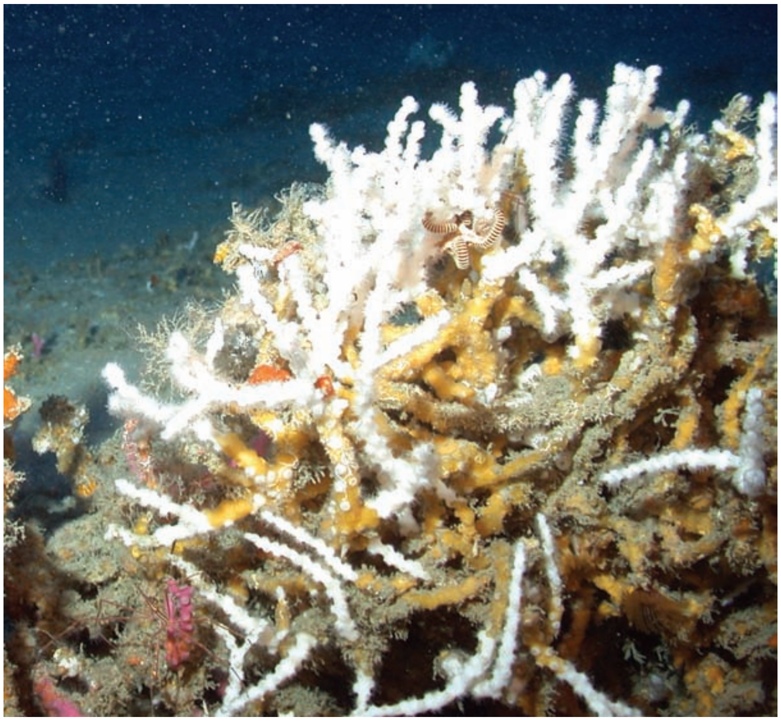

Figure 1.9 *Oculina varicosa* in the *Oculina* HAPC. Photo credit: L. Horn, NOAA Undersea Research Center at UNC-Wilmington.

(max = 405 mm diameter), but the fecundity is much lower (a total fecundity of 10- 60 oocytes per polyp vs. 3,000 oocytes for *L. pertusa*; Waller and Tyler 2005).

I.A.1.c.iii. *Oculina varicosa* Lesueur, 1821

Description: *Oculina varicosa* (the ivory tree coral) is an important deep reef-building species that forms thickets of large branched colonies along the eastern Florida shelf.

Distribution: *O. varicosa* is restricted to the western Atlantic, including the Caribbean and Gulf of Mexico, Florida to North Carolina and Bermuda (Verrill 1902; Reed 1980). The deep-water *Oculina* reefs, however, are only known off the east coast of central Florida at depths of 70-100 m (Avent et al. 1977; Reed 1980, 2002b), occurring as offshore banks and pinnacles up to 35 m in height (Reed 2002b; Reed et al. 2005) (Figure 1.9).

Depth Range: Depth range of *O. varicosa* has been reported from 2-152 m (Verrill 1902; Reed 1980). It is an unusual coral in that it occurs in both shallow and deep waters (Reed 1981), and is facultatively zooxanthellate, containing symbiotic algae only in shallow waters (2-45 m).

Morphology: There are morphological differences between the shallow and deep-water colonies of *O. varicosa*. Shallow populations (2-45 m) are dominated by stout, thickly branched colonies, possibly in response to wave action (Verrill 1902; Reed 1980). Deeper colonies (49-152 m) are more fragile and taller than their shallow counterparts, with colonies growing up to 2 m in diameter and height (Reed 1980, 2002b).

Growth and Age: The linear branch growth rate of *O. varicosa* appears to be faster in deeper water (16 mm yr^{-1} at 80 m) where zooxanthellae are absent, than at 6 m depth (11 mm yr^{-1}). These differences may be due to environmental factors such as greater sedimentation rates and more variable temperature extremes, as well as morphological differences in which shallow colonies put more energy into diameter than height (Reed 1981, 2002b).

Reproduction: *O. varicosa* is a gonochoristic broadcast spawning species, producing large numbers of small eggs which are released annually in August and September (Brooke and Young 2003). Planulae have a relatively long

Figure 1.10 *Madracis myriaster* specimen (30.2 cm) collected from 200 m off Jamaica. Photo credit: S. Lutz

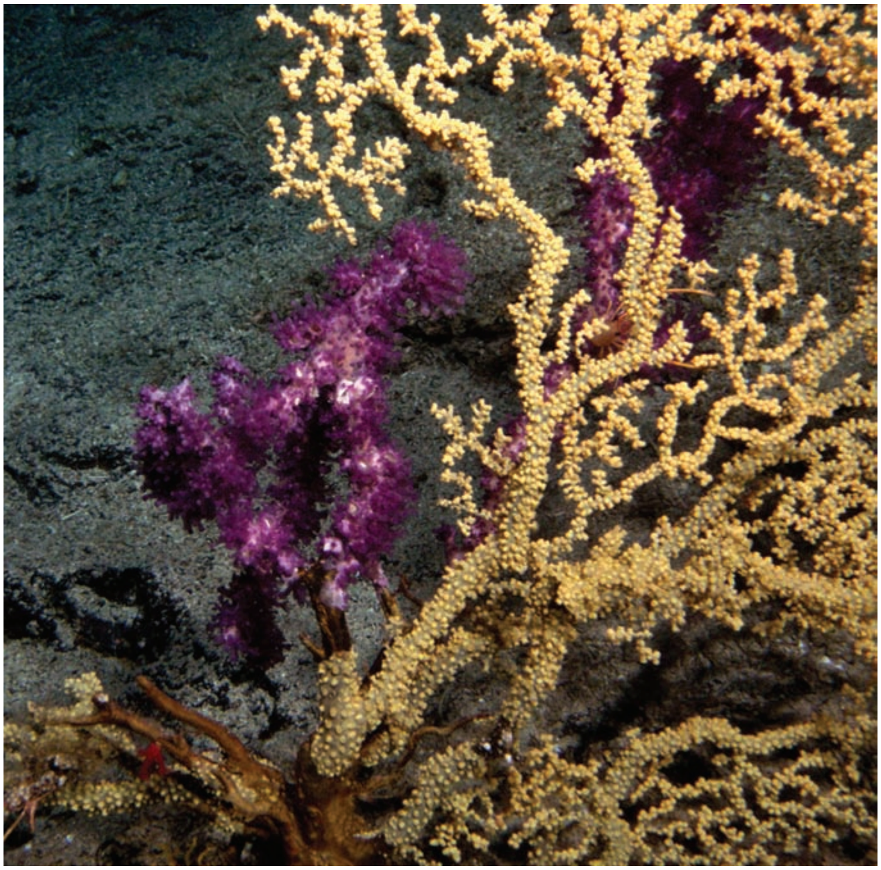

Figure 1.11 Gold coral (*Gerardia* sp.) in Hawaii with a purple octocoral *Clavularia grandiflora* growing on it. Photo credit: A. Baco.

planktonic period (at least 22 days) (Brooke and Young 2003, 2005), which provides the potential for widespread transport between deep reef tracks as well as cross-shelf transport (Smith 1983). This strategy may help facilitate recovery of degraded areas, although very little coral recruitment has been observed to date in damaged areas (Brooke and Young 2003).

I.A.1.D. FAMILY POCILLOPORIDAE

I.A.1.d.i. *Madracis myriaster*
(Milne-Edwards and Haime, 1849)

Description: *Madracis myriaster* (Figure 1.10) is a deep-water species in the predominantly shallow-water family Pocilloporidae. It is reported as a primary framework-builder of Caribbean deep coral banks off Colombia (Reyes et al. 2005). It is considered a major structure-forming coral in the southeast U.S. (Chapter 6) and the Caribbean (Chapter 8).

Distribution: *M. myriaster* is endemic to the tropical northwestern Atlantic Ocean (Cairns et al. 1999), between 7° and 29° N latitude. In U.S. waters it occurs in the Gulf of Mexico, Straits of Florida, off the Atlantic coast of Florida and Georgia, and in the U.S. Caribbean off Puerto Rico and the U.S. Virgin Islands.

Depth Range: *M. myriaster* is found at depths ranging from 37-1,220 m (Chapter 8; Cairns 1979).

Morphology: *M. myriaster* is a branching species that forms broad, bushy colonies of 30-40 cm in height (Cairns 1979).

Growth, Age, and Reproduction: Limited information is available.

I.A.2. ORDER ZOANTHIDEA

Zoanthids are colonial, sea anemone-like anthozoans, mostly occurring in shallow tropical waters. While most of the more than 100 species of zoanthids do not form skeletal structures, deep-water gold corals are one taxon found in this order that does form rigid skeletons and grows to large sizes.

I.A.2.A. FAMILY GERARDIIDAE

I.A.2.a.i. *Gerardia* spp. (Gold corals)

Description: *Gerardia* spp. form branching colonies that have an axis of dense, hard proteinaceous material. The skeleton of gold corals is used in the manufacture of coral jewelry. Gold corals were harvested from the Makapu'u Bed off Hawaii between 1974 and 1978 (Chapter 4). The taxonomy of this group is not well defined.

Distribution: Gold corals in the family Gerardiidae are found on hard substrates such as basalt and carbonate hardgrounds. These forms of substrate are common on seamounts in the north and equatorial Pacific and Atlantic Oceans.

Depth Range: In U.S. waters, gold corals have

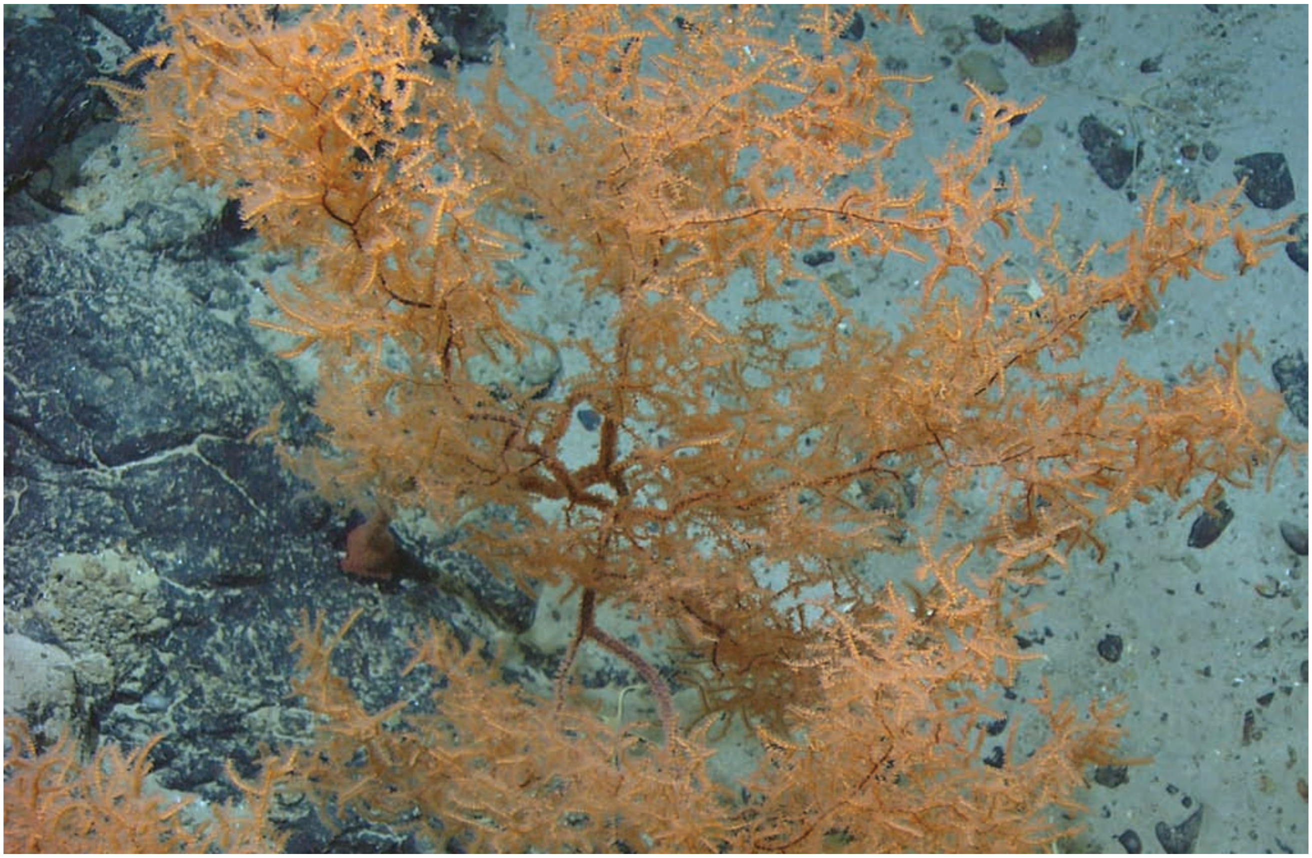

Figure 1.12 A bushy black coral on Manning Seamount. Photo credit: The Mountains in the Sea Research Team, the IFE crew, and NOAA-OE.

been reported in the Hawaiian Archipelago and the Emperor Seamounts at depths of 350-600 m (Chapter 4) and in the Straits of Florida at depths around 600 m (Messing et al. 1990).

Morphology: These corals form a rigid, branching, tree-like structure that can attain a height of up to 3 m (Figure 1.11).

Growth and Age: Gold corals appear to be very long-lived. A colony of *Gerardia* sp. collected off Little Bahama Bank was estimated to be 1,800 years old (Druffel et al. 1995), and colonies off Hawaii have been aged at 450 to 2,742 years (Roark et al. 2006), placing them among the oldest known marine organisms.

Reproduction: Gold corals, like some other zoanthids, can be epizoic on other invertebrates; the larval stages settle out on other species of corals, particularly bamboo corals, and eventually overgrow the colony. Zoanthids are known to broadcast spawn during mass spawing events.Several species have separate sexes, while some are also hermaphroditic (Ryland and Babcock 1991). Reproductive strategies of gold coral are unknown.

I.A.3. ORDER ANTIPATHARIA (BLACK CORALS)

Description: About 250 species of black coral are currently known. They do not form reefs, but like gorgonians and gold corals, large branching species can provide habitat for numerous other species. Though black corals are found in all U.S. regions they are best documented off Hawaii where they are commercially harvested for jewelry (Chapter 4; Grigg 2002). The order Antipatharia has recently been the subject of significant taxonomic revision (e.g., Opresko 2001, 2002, 2003, 2004), and several new families have been proposed. A number of species in several families have been identified as important structure-forming corals in U.S. waters (Appendix 1.1 and 1.2).

Distribution: Antipatharians, commonly known as black corals, are found in all oceans, but are generally most common in deep-water habitats of tropical and subtropical oceans. They are generally anchored with a strong holdfast to hard substrate near drop-offs, terraces, ledges, and reef slopes in areas swept by strong currents. Black corals have recently been reported from cruises to seamounts (Figure 1.12) in the Gulf of Alaska (Baco and Cairns 2005), Davidson Seamount off the California Coast (DeVogelaere et al. 2005), the New England Seamounts in the Atlantic (NOAA 2004), and in the northwestern Gulf of Mexico (E. Hickerson and G.P. Schmahl pers. comm.).

Depth Range: Antipatharians are usually found at depths greater than 20 m, to a maximum of nearly 3,000 m (Etnoyer and Morgan 2005). Isolated colonies of deep-water species can be found in shaded areas as shallow as 4 m (Etnoyer and Morgan 2005), and a common temperate species from New Zealand (*Antipathes fiordensis*) is most abundant between 10 and 35 m depth (Grange 1985).

Morphology: Antipatharians are hexacorals with branched (bushy, pinnate or fan-shaped) or unbranched (whip-like) skeletons covered with small spines or knobs and polyps that can be rust, yellow, green or white in color (Figure 1.12). The polyps possess six unbranched, non-retractile tentacles, a feature that distinguishes them from gorgonians. The skeleton is black or dark brown in color and consists of chitin fibrils embedded in a protein matrix deposited as a series of layers or growth bands.

Growth and Age: Black corals are known to achieve heights that exceed 3 m. Linear growth rates reported for black corals from temperate regions are much slower (e.g., *Antipathes fiordensis;* 1.6-3.0 cm yr^{-1}; Grange 1997) than those of two commercially important species from Hawaii (*Antipathes dichotoma,* 6.42 cm yr^{-1} and *Antipathes grandis,* 6.12 cm yr^{-1}; Grigg 1976). While *A. fiordensis* is reported to reach sexual maturity at 70-105 cm, corresponding to a minimum age of 31 years (Parker et al. 1997), *A. dichotoma* and *A. grandis* are estimated to reach sexual maturity between 10-12.5 years (at heights of 64-80 cm), and can live about 40 years (Grigg 1976). The age of another Hawaiian black coral occurring in deeper water (*Leiopathes glaberrima*) was recently estimated at around 2,377 years (Roark et al. 2006), and other species have been estimated to live longer than a century (Love et al. 2007; Williams et al. in press).

Reproduction: *A. fiordensis*, a species from a New Zealand fjord, is a gonochoristic broadcast spawner with seasonal reproductive patterns (Parker et al. 1997). Mature oocytes are 100-140 µm in diameter and female colonies produced 1.3-16.9 million oocytes. As with all colonial corals, the larger colonies dominate the reproductive output of the population (Miller 1996).

I.B. SUBCLASS OCTOCORALLIA

The subclass Octocorallia includes gorgonians (sea fans and sea whips), true soft corals, stoloniferans, and sea pens, all groups that include deep-water species, as well as the order Helioporacea. The latter includes the small family Lithotelestidae (Bayer and Muzik 1977) with at least one deep coral species in the Caribbean (Chapter 8) and the family Helioporidae, which contains one extant shallow-water species, the blue coral. Octocorals are distinguished from other anthozoans by the presence of eight feather-like (pinnate) tentacles. Octocorals can form large, long-lived colonies with many (thousands) of tiny polyps, but they do not form complex reef structures. They all contain calcareous spicules within their tissue (coenochyme) and some (order Gorgonacea) also have a central proteinaceous rod with embedded calcareous spicules or heavily calcified skeletal elements that alternate with non-calcified gorgonin elements. Currently about 2,700 species of octocorals have been described; most occur in shallow water, although several hundred species also occur in deep water. In deep-water habitats where stony corals are less abundant, such as seamounts and at high latitudes, octocorals are more prevalent and form the basis of the coral ecosystem. Gorgonians, true soft corals, and stoloniferans are now commonly grouped together within the single order Alcyonacea (Bayer 1981; Fabricius and Alderslade 2001), but are discussed as separate taxa in this report to provide additional detail regarding the distribution of these important functional groups of corals. The orders Helioporacea and Pennatulacea are clearly delineated as separate orders from the remaining octocorals.

I.B.1. ORDER ALCYONACEA (TRUE SOFT CORALS)

In general, these soft corals are less important structure-forming species than are many gorgonians, although the families Alcyoniidae and Nephtheidae include deep-water species that achieve relatively large sizes (Watling and Auster 2005). Soft corals of the genus *Eunephthea* (formerly *Gersemia*) are widespread and are the most abundant corals in the Bering Sea (Chapter 2). True soft corals of the order Alcyonacea generally lack a rigid internal skeleton for support, but have separate calcareous spicules embedded in the fleshy coenochyme. Stoloniferans, now included in the Alcyonacea, have small polyps that are often connected to each other by a thin runner or stolon. With the exception of the tropical shallow-water organ-pipe coral (*Tubipora musica*), most are not important structure-forming corals. However, a few species can form extensive mats on hard surfaces such as rocks, other corals, and sponges (Stone 2006).

I.B.2. ORDER GORGONACEA (SEA FANS)

Major structure-forming families in the order Gorgonacea include Isididae, Coralliidae, Paragorgiidae, and Primnoidae (Morgan et al. 2006), with species in the families Plexauridae, Acanthogorgiidae, Ellisellidae, Chrysogorgiidae, and Anthothelidae providing structure to some degree (Appendix 1.1 and 1.2). At least 12 families are known to occur in waters deeper than 200 m (Etnoyer et al. 2006). Gorgonians are the most important structure-forming corals in the Gulf of Alaska and the Aleutian Islands, where they form both single- and multi-species assemblages (Chapter 2). For example, *Primnoa pacifica* forms dense thickets in the Gulf of Alaska (Krieger and Wing 2002), while as many as 10 species are found in Aleutian Island coral gardens (Stone 2006). Most gorgonians have a solid proteinaceous (gorgonin) central axis with embedded calcareous sclerites that provide support, covered by a thin layer of tissue (coenenchyme and polyps) with embedded calcareous spicules (Fabricius and Alderslade 2001). They often exhibit a branching morphology, can occur at high density and cover, and reach considerable size (>3 m tall), thus providing structure and habitat for associated fauna.

I.B.2.A. FAMILY ISIDIDAE (BAMBOO CORALS)

Description: Isididae is a large family with over 150 species of mostly deep-water corals. The most common deep-water genera are *Acanella, Isidella* and *Keratoisis*. *Acanella arbuscula*, a species occurring in the northwestern Atlantic (Chapters 5 and 7) is unusual in that it anchors in mud rather than on hard substrata (Mortensen and Buhl-Mortensen 2005a). Several species are collected for jewelry.

Distribution: Bamboo corals are thought to have a cosmopolitan distribution and important structure-forming species have been identified in the Gulf of Mexico, the Southeast, Hawaii, the West Coast, the northeast Pacific and Indo-Pacific (Fabricius and Alderslade 2001; Etnoyer and Morgan 2003; Appendix 1.1 and 1.2).

Depth Range: In general bamboo corals occur below 800 m (Etnoyer and Morgan 2005), with the deepest recorded at 4,851 m (Bayer and Stefani 1987). In Alaska bamboo corals are observed between 400 and 2,827 m but have been collected from depths of 3,532 m (Chapter 2). However, four genera have been reported from tropical Indo-Pacific reefs at depths of 10-120 m (Fabricius and Alderslade 2001).

Morphology: Colonies can be whip-like but are usually branched, bushy or fan-like (Figure 1.13) and can range in size from tens of centimeters to over a meter (Verrill 1883). Colonies have a distinctly articulated skeleton of heavily calcified internodes and proteinaceous gorgonin nodes (a stiff leathery matrix consisting of protein and mucopolysaccharides). The alternating segments give the isidid branches a unique bamboo-like appearance (Figure 1.13), hence the name "bamboo-coral."

Growth and Age: Recent studies by Andrews et al. (2005a,b) have estimated radial growth rates for bamboo corals that ranged from approximately 0.05 (age 150 years) to 0.117 mm yr^{-1} (age 43 years). Linear growth rates up to 30 mm yr^{-1} have been estimated for *Lepidisis* sp. in New Zealand waters (Tracey et al. in press).

Reproduction: Reproductive strategy is thought to be similar to that of other octocorals with colonies having separate sexes and gametes

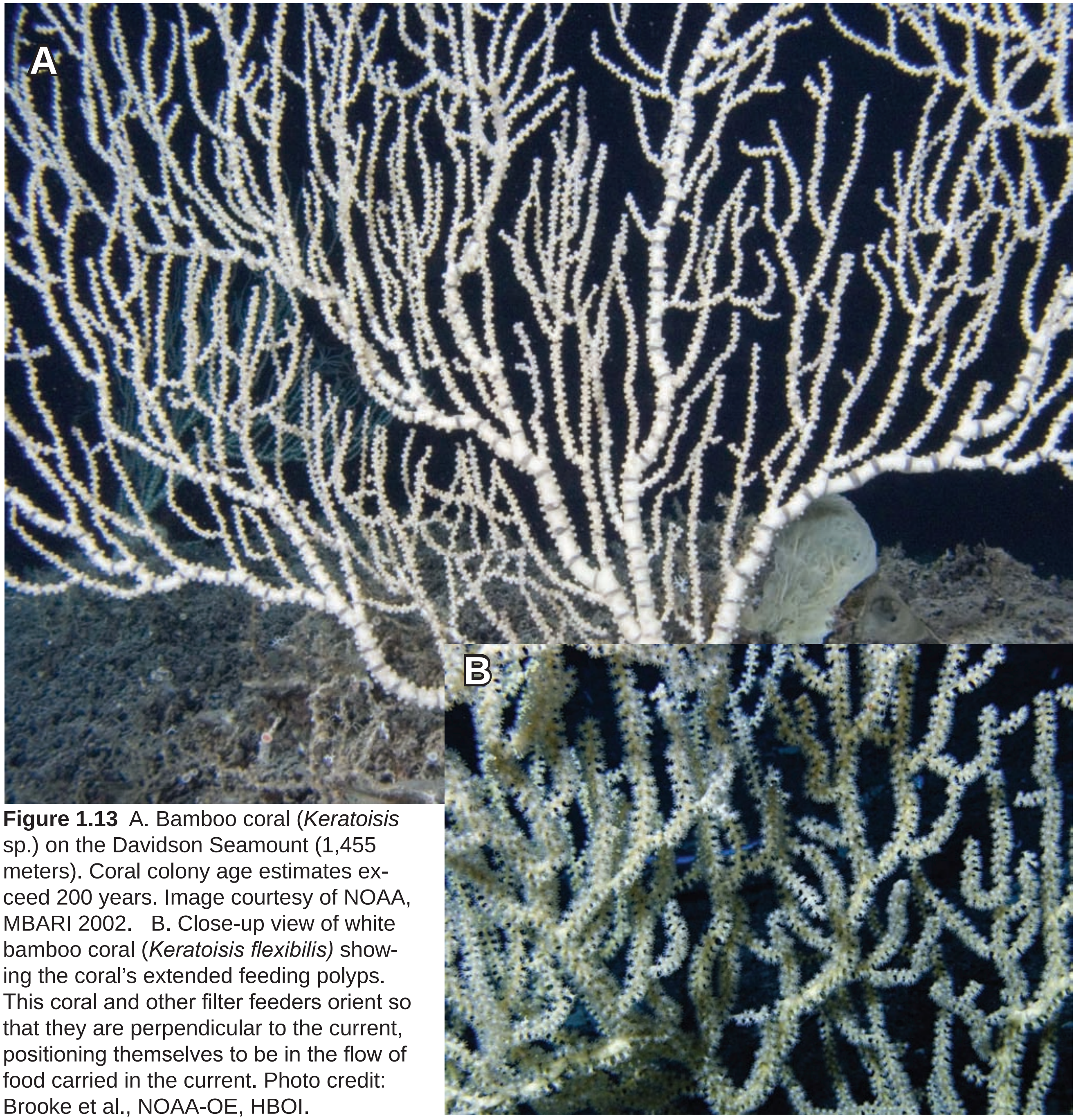

Figure 1.13 A. Bamboo coral (*Keratoisis* sp.) on the Davidson Seamount (1,455 meters). Coral colony age estimates exceed 200 years. Image courtesy of NOAA, MBARI 2002. B. Close-up view of white bamboo coral (*Keratoisis flexibilis)* showing the coral's extended feeding polyps. This coral and other filter feeders orient so that they are perpendicular to the current, positioning themselves to be in the flow of food carried in the current. Photo credit: Brooke et al., NOAA-OE, HBOI.

being broadcast into the water column in a synchronous manner (Fabricus andAlderslade 2001).

I.B.2.B. FAMILY CORALLIIDAE (RED AND PINK CORALS)

Description: The family Coralliidae was recently divided into two genera *Paracorallium* and *Corallium* (Bayer and Cairns 2003). The only known populations of pink and red corals large enough to support commercial harvest are found north of 19º N latitude, including seven species harvested in the western Pacific and one collected in the Mediterranean. All species of *Corallium* identified in the Southern Hemisphere occur in low abundance (Grigg 1993). The family Coralliidae contains the most valuable taxa of precious corals. It is traded in large quantities as jewelry and other products, and as raw coral skeletons. Of the 31 known species in this family, seven are currently used in the manufacture of jewelry and art (Cairns in press; Figure 1.14a). One species, *Corallium rubrum*, has been harvested for at least 5,000 years from the Mediterranean. Other species have been harvested for 200 years in the western Pacific off islands surrounding Japan, Taiwan, and the

Figure 1.14a Pink coral necklaces for sale in Japan. Photo credit: Andy Bruckner, NOAA.

Figure 1.14b *Corallium* sp., with deep purple *Trachythela* octocoral, brittle stars, crinoids and sponges. Photo credit: The Mountains in the Sea Research Team, the IFE crew, and NOAA-OE.

Philippines, and for 40 years in the western Pacific off Hawaii and international waters around Midway Islands (Grigg 1993).

Distribution: The family is widely distributed throughout tropical, subtropical, and temperate oceans including five species from the Atlantic Ocean, one from the Mediterranean Sea, two from the Indian Ocean, three from the eastern Pacific Ocean, and 15 from the western Pacific Ocean (Grigg 1974; Weinberg 1976; Cairns in press). In U.S. waters, they are best known from banks off Hawaii (Chapter 4). They have also been found on seamounts in the Gulf of Alaska (Baco and Shank 2005; Heifetz et al. 2005), Davidson Seamount off the California coast (DeVogeleare et al. 2005), and the New England Seamounts in the Atlantic (Morgan et al. 2006; Figure 1.14b).

Depth Range: Depths for this family range from 7 m to 2,400 m (Bayer 1956; Weinberg 1976).

Morphology: *Corallium* spp. have a hard calcareous skeleton with an intense red or pink color (Figure 1.14a). They are sedentary colonial cnidarians with an arborescent growth form, attaining heights ranging from 50-60 cm (*C. rubrum*) to over 1 m (U.S. Pacific species).

Growth and Age: *Corallium* species are very slow growing, but individual colonies can live for 75-100 years. For example, *C. rubrum* exhibits average annual growth rates of 2-20 mm in length and 0.24-1.32 mm in diameter. *Corallium secundum,* a commercially valuable species found off Hawaii (Chapter 4), is reported to increase in length at rates of about 9 mm yr^{-1} (Grigg 1976). Natural mortality rates of *C. secundum* vary between 4-7%, with turnover of populations occurring every 15 to 25 years (Grigg 1976).

Reproduction: Aspects of reproductive biology have been studied for *C. rubrum* and *C.*

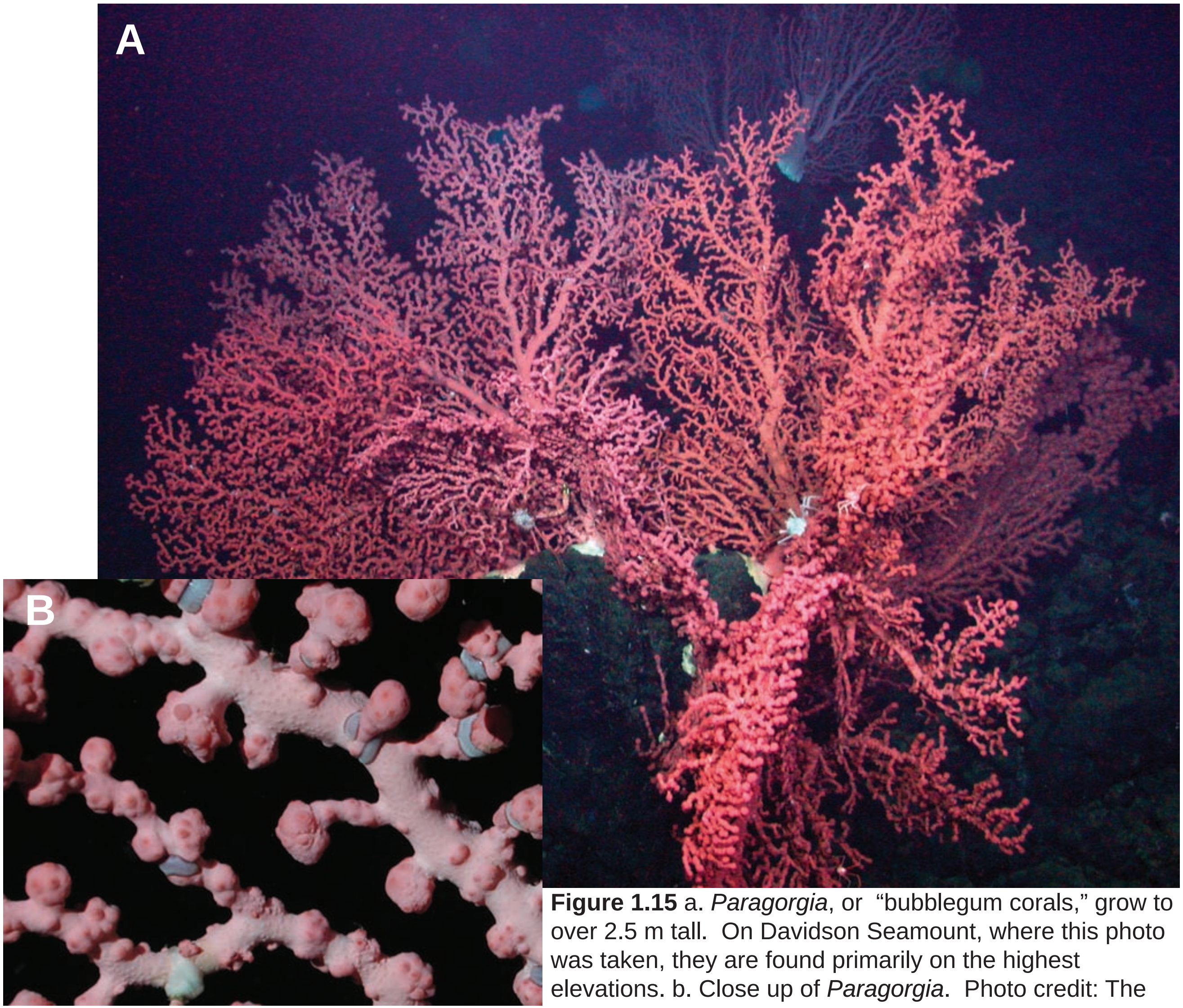

Figure 1.15 a. *Paragorgia*, or "bubblegum corals," grow to over 2.5 m tall. On Davidson Seamount, where this photo was taken, they are found primarily on the highest elevations. b. Close up of *Paragorgia*. Photo credit: The Davidson Seamount Expedition, MBARI, and NOAA-OE.

secundum only. These species have separate sexes and an annual reproductive cycle. *C. rubrum* reaches maturity at 2-3 cm height and 7-10 years of age[2] (Santangelo et al. 2003; Torrents et al. 2005); *C. secundum* reaches maturity at 12 years (Grigg 1993). Usually, *C. rubrum* is a brooder with a short-lived passive larval stage while *C. secundum* is a broadcast spawner. Planulation occurs once per year, primarily during summer. Larvae remain in the water column for a few days (4-12 days in the laboratory) before settling in close proximity to parent colonies (Santangelo et al. 2003).

I.B.2.C. FAMILY PARAGORGIIDAE (BUBBLEGUM CORALS)

Description: The small family Paragorgiidae, commonly referred to as "bubblegum corals," has recently been expanded to includes nine known species in the genus *Paragorgia*, (Sanchez 2005). These corals are large branching gorgonians (Figure 1.15) and are thought to reach the largest size of any sedentary colonial animal. For example, colonies of *Paragorgia arborea* in New Zealand have been reported to reach 10 m in height (Smith 2001).

Distribution: *P. arborea* has been reported to have a bipolar distribution, occurring in deep waters of the Southern Hemisphere and in the North Atlantic and Pacific Oceans (Grasshoff 1979). In the U.S., *P. arborea,* occurs in the submarine canyons off Georges Bank at depths of 200-1,100 m, where it can occur in dense

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[2] In earlier studies, more than 50% of colonies were reported to reach sexual maturity at 2 years, and all colonies over 5 years were fertile. Recent aging studies suggest that these reports underestimated the true age of reproductive maturity by 3-4 years (Marschal et al. 2004).

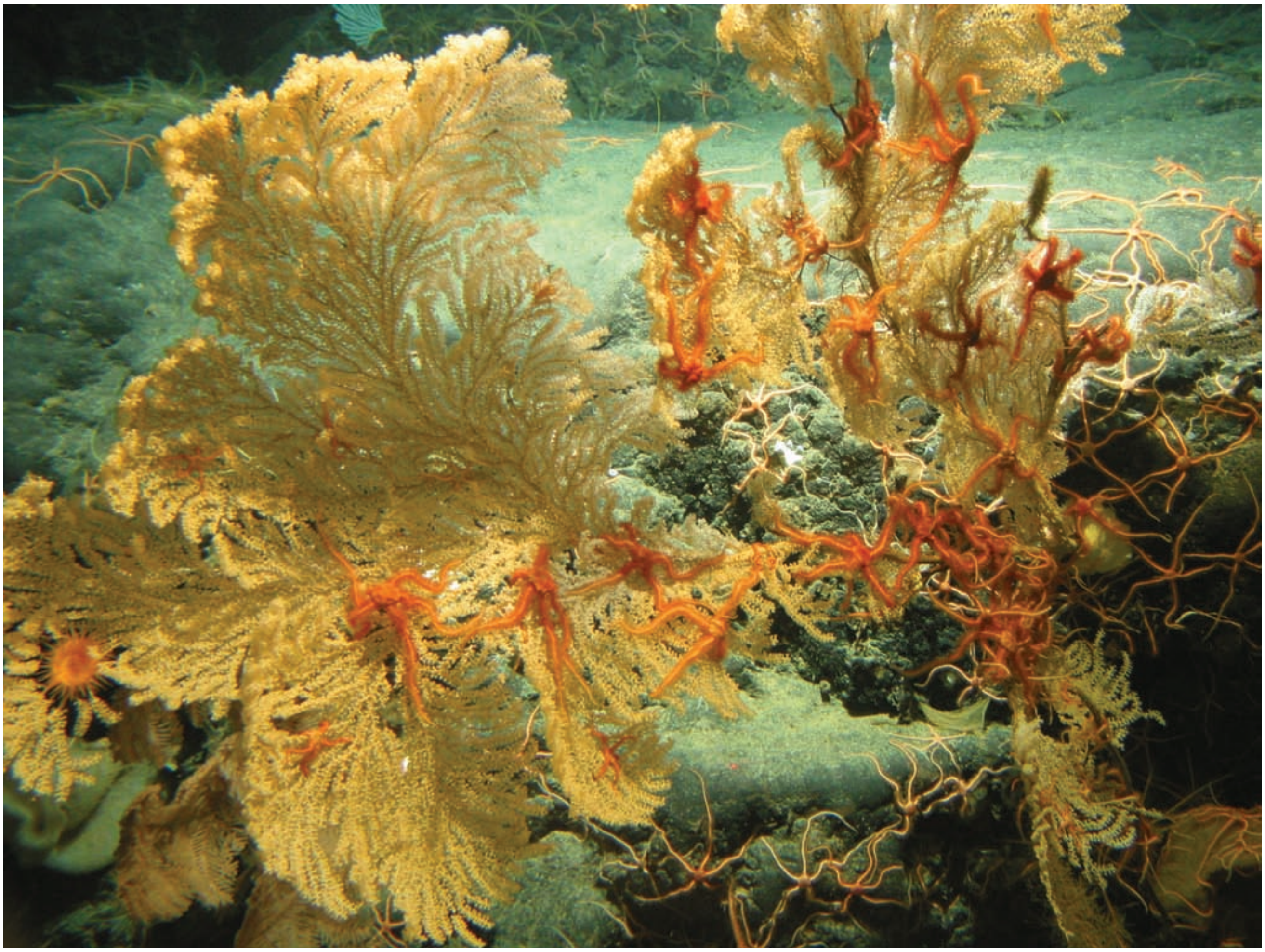

Figure 1.16. Large primnoid coral with associated brittle stars on Dickinson Seamount, Gulf of Alaska. Photo credit: The Gulf of Alaska Seamount Expedition, and NOAA-OE.

thickets. It is also reported to be common in the Aleutian Islands of Alaska (Chapter 2; Etnoyer and Morgan 2003) and on Alaskan seamounts and Davidson Seamount off California. Recent analysis of specimens of *Paragorgia arborea* collected off the Atlantic coast of Canada and a morphologically similar *Paragorgia* sp. from the Pacific were genetically dissimilar (Strychar et al. 2005).

Depth Range: Paragorgiids have been found in the Pacific at depths ranging from 19-1,925 m (Etnoyer and Morgan 2003). In the northeast Atlantic they have been found to depths of 1,097 m (Mortensen and Buhl-Mortensen 2005a).

Morphology: Like other gorgonians, colonies have a proteinaceous skeleton with embedded spicules covered in a soft tissue, and polyps have eight feather-like tentacles. *P. arborea* exhibits distinct intraspecific color variation, with red, pink, orange, and white morphs reported.

Growth and Age: Growth rates of bubblegum coral are not well defined. Mortensen and Buhl-Mortensen (2005b) report estimates of linear growth rates for *P. arborea* in New Zealand and Norway between 2.2-4.0 cm yr^{-1} and 0.8-1.3 cm yr^{-1} respectively. Andrews et al. (2005a) estimated a Pacific species to have grown at a minimum of 0.5 cm yr^{-1} based on a single observation of a 20 cm coral on a telegraph cable submerged for 44 years.

Reproduction: Reproductive strategy is thought to be similar to that of other octocorals with colonies having separate sexes and gametes being broadcast into the water column in a synchronous manner (Fabricus and Alderslade 2001).

I.B.2.D. FAMILY PRIMNOIDAE

Description: Primnoidae is a large family (>200 species) that includes a number of conspicuous and abundant branching species in the genera

Primnoa (the red tree corals) and *Callogorgia.* These corals attach to rocky outcrops and boulders in the presence of strong currents.

Distribution: They are among the most common large gorgonians, occurring in dense thickets in some regions and, in the U.S., appear to reach their highest abundance in Alaska (Figure 1.16; Chapter 2; Etnoyer and Morgan 2005).

Depth Range: Etnoyer and Morgan (2003) found the northeast Pacific depth range for Primnoidae to be 25-2,600 m, with the majority occurring shallower than 400 m. *Primnoa resedaeformis* occurs from 91-548 m in the northwestern Atlantic, where it is among the most abundant species (Cairns and Bayer 2005).

Morphology: *Primnoa* spp. form a branching tree-like structure with a skeleton composed of calcite and a hornlike protein called gorgonin.

Growth and Age: *Primnoa* spp. can reach over 7 m in height (Krieger 2001). Growth of deepwater primnoids is slow, with growth rates estimated at 1.60-2.32 cm in height and 0.36 mm in diameter per year for a *Primnoa* sp., found in the Gulf of Alaska (Andrews et al. 2002)[3]. Mortensen and Buhl-Mortensen (2005b) estimated growth rates for *P. resedaeformis* in the Canadian Atlantic, at 1.8–2.2 cm per year for young colonies (<30 years) and 0.3–0.7 cm per year for older colonies, with a maximum age of 60 years fro the sampled corals. Risk et al. (1998, 2002) estimated large colonies of *P. resedaeformis*, sampled from Nova Scotia to be hundreds of years old.

Reproduction: Reproductive strategy is thought to be similar to that of other octocorals with colonies having separate sexes and gametes being broadcast into the water column in a synchronous manner (Fabricus and Alderslade 2001).

I.B.3. ORDER PENNATULACEA (SEA PENS)

Description: Pennatulaceans are a diverse but poorly known group of octocorals that include 16 families, most of which live in the deep sea. They are uniquely adapted to soft-sediment areas (Figure 1.17); many are able to uncover themselves when buried by shifting sands and re-anchor when dislodged. They burrow and anchor by means of peristaltic contractions against the hydrostatic pressure of the peduncle (Williams 1995). Certain species, such as *Ptilosarcus gurneyi*, are capable of completely withdrawing into the sediment (Birkeland 1974). Though pennatulaceans are common in many parts of the U.S. Exclusive Economic Zone (EEZ) their contribution as habitat and to diversity of associated species is not well documented or understood. Brodeur (2001) found dense aggregations of rockfish (*Sebastes alutus*) associated with “forests” of the sea pen *Halipteris willemoesi* in the Bering Sea. They are probably not structure-forming in the same sense as other coral groups discussed above but they may provide important habitat in areas that cannot be colonized by structure-forming gorgonian and scleractinian corals. Given their widespread distribution in soft-sediment areas, sea pens may be the most abundant deep coral worldwide.

Distribution: Sea pens are found in all the world’s oceans (Fabricius and Alderslade 2001). In Alaskan waters a few species are known to form extensive groves (Figure 1.17). The South Atlantic Bight and Gulf of Mexico appear to be relatively depauperate in comparison to other U.S. regions (Chapters 6 and 7).

Depth Range: Pennatulaceans are known from shallow waters to the abyssal plains. Most

Figure 1.17 Dense groves of the sea pen *Ptilosarcus gurneyi* are found on soft-sediment shelf habitats in the Gulf of Alaska and Aleutian Islands. Photo credit: P. Malecha, NOAA’s National Marine Fisheries Service.

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[3] The authors identified this species in Alaska as *Primnoa resedaeformis*, which is now thought to occur only in the Atlantic.

pennatulaceans live in the deep sea, and the deepest known corals are sea pens in the genus *Umbellula*, which have been recorded at depths greater than 6000 m (Williams 1999).

Morphology: The sea pens and sea pansies (order Pennatulacea) differ from other octocorals in that there is a large, primary polyp that gives rise to secondary dimorphic polyps (autozooids and siphonozooids), and a stem-like base or foot (peduncle) that is anchored in the sand. Many species are elongate and whip-like and are supported by an internal calcareous axis. *Umbellula*, a genus found on the Atlantic abyssal plain and deep-water areas of the North Pacific, is characterized by a long stalk that can be a meter or more in length, with a series of secondary polyps mounted at the end; another species from Alaska, *H. willemoesi*, attains a height greater than 3 m (R. Stone, personal observation).

Growth and Age: Wilson et al. (2002) report growth rates for *H. willemoesi* of 3.6 to 6.1 cm yr^{-1} depending on size with an estimated longevity approaching 50 years for moderately sized specimens.

Figure 1.18 Stylaster coral. Photo credit: Phillip Colla Photography, Oceanlight, Carlsbad, CA.

Reproduction: Sea pens are known to be broadcast spawners but other reproductive information is limited.

II. CLASS HYDROZOA

Hydrozoans are a mostly marine group of cnidarians including the hydroids and hydromedusae (e.g., jellyfish). Most hydrozoans alternate between a polyp and a medusa stage. One order, Anthoathecatae, contains species with calcium carbonate skeletons and are classified as coral-like organisms: the stylasterid corals (suborder Filifera, family Stylasteridae), which include many deep-water species, and the shallow-water fire corals (suborder Capitata, family Milleporidae).

II.A.1. ORDER ANTHOATHECATAE

II.A.1.a Family Stylasteridae
(Stylasterid corals)

Description: The order Anthoathecatae, previously identified as Filifera (now suborder Filifera) or Stylasterina, contains the stylasterid corals (also known as lace corals) in the family

Stylasteridae, a group of calcareous encrusting or branching colonial species. Stylasterids are often confused with stony corals due to their calcareous nature but the resemblance is superficial.

Distribution: As a group, the stylasterid corals occur worldwide and at a wide range of depths. About 90% of the 250 extant stylasterid species live exclusively in deep waters occurring as deep as 2,700 m (Cairns 1992a). Other species, such as the Pacific *Stylaster* sp. (Figure 1.18), may occur in relatively shallow water. *Stylaster*, *Distichopora,* and *Pliobothrus* are among the better-known genera in this family. In U.S. waters they have been reported from most regions except the northern Gulf of Mexico (Cairns 1992b), but appear to be of particular importance as structure forming components in the Straits of Florida (Chapter 7) and Alaska (Chapter 2).

Depth Range: Stylasterids may be found in shallow-water reef systems in only a few meters of water; deep-water species occur from 79-2,700 m depth (Broch 1914; Cairns 1992a; Etnoyer and Morgan 2003).

Morphology: Stylasterids have a hard calcium carbonate skeleton covered with thousands of pinhole-sized pores. Each pore contains a single gastrozooid, a stout feeding polyp with eight tentacles. These are surrounded by 5-9 dactylozooids, which are thin sensory/stinging polyps devoid of tentacles but armed with batteries of nematocysts. Though they have a wide range of morphological forms, most have extremely fragile branches and are highly susceptible to physical damage. In Alaska some species, e.g.,*Stylaster cancellatus*, may grow to almost one meter in height (R. Stone, pers. comm.).

Growth and Age: Limited information is available.

Reproduction: Stylasterids are usually gonochoristic and fertilization is internal. The male and female reproductive structures or gonophores, develop in epidermally lined cavities called ampullae (rounded inclusions in the calcareous skeleton). These ampullae usually appear as small hemispheres on the surface of the colony, but occasionally are completely submerged in the calcareous coenosteum. The larvae develop in the gonophores and leave via small pores near the ampullae (Ostarello 1973, 1976). Larvae of the species studied to date are short-lived and non-dispersive (Ostarello 1973), which has implications for ecosystem recovery from disturbance (Brooke and Stone in press).

THREATS TO DEEP CORAL ECOSYSTEMS

Structure-forming deep corals are generally slow growing and fragile, making them and their associated communities vulnerable to human-induced impacts, particularly physical disturbance. With the exception of a few areas (e.g., the *Oculina* Banks), the extent of habitat degradation resulting from these threats is largely unknown although there is increasing information on significant impacts in some areas. Activities that can directly impact deep coral communities include fishing using bottom-tending fishing gear, deep coral harvesting, oil and gas and mineral exploration and production, and submarine cable/pipeline deployment. Invasive species, climate change and ocean acidification represent additional serious threats. Though not exhaustive, this list does include the more important activities that may alter deep coral habitat. The extent of impact from these activities and the type of stressors that cause the most degradation vary among regions. For example, impacts from mobile bottom-tending fishing gear are the largest potential threat in many areas of Alaska, but are not an issue in the U.S. Pacific Island regions where trawling is banned. In Hawaii, the harvest of certain deep coral species – including black corals, pink coral, gold coral, and bamboo corals – is permitted and regulated by the Precious Coral Fishery Management Plan (FMP) in federal waters and under Hawaii Administrative Rules in state waters.

Bottom Trawling and Other Bottom-tending Fishing Gear Impacts

A number of different types of fishing gear impact the seafloor and pose potential threats to deep coral communities. Table 1.2 lists different types of fishing gear known to impact deep corals, a description of the gear, their impacts, and the level of severity as a result of these interactions. Bottom trawling is the largest potential threat to deep coral habitat for several reasons: the

Table 1.2 Major bottom-contact fishing gear types used in U.S. fisheries and a description of their potential impact on structure-forming deep corals. This table identifies only the potential severity of disturbance to deep corals if they are encountered by the gear based on reported instances of interactions. It is not meant to indicate that interactions between these gears and deep corals currently occur in the U.S. EEZ. Regional Fishery Management Councils have analyzed potential gear impacts and have proposed measures to minimize to the extent practicable adverse impacts of these gears on essential fish habitat (see Section on U.S. Conservation and Management Measures). **NRC 2002; † High 1998; § NMFS 2004; ‡ Eno et al. 2001; Σ Stone et al. 2005.

Major types of bottom-tending fishing gear	Gear types that may impact deep corals	Description of gear	Description of impact on corals	Potential severity of disturbance
Trawls	*Bottom/ otter trawls*	A large net is held open by two doors and dragged behind a fishing boat along the seafloor; gear in contact with seafloor can be 30-100 m in length; primarily used to harvest demersal finfish and rock shrimp	Incidentally removes, displaces or damages corals**	High
	Mid-water trawls	Similar type of gear to the bottom trawl but designed to harvest pelagic fish species; no protective gear on the footrope	May come in contact with bottom during fishing, which can remove, displace or damage corals §	Low
Dredges	*Scallop dredges*	A large steel frame is dragged behind a fishing boat along the seafloor; specifically used to harvest scallops	Incidentally removes, displaces or damages corals Σ	High
Longlines	*Bottom-set longlines/ demersal longlines*	A nylon or poly line with up to thousands of attached hooks; deployed along the seafloor in lengths up to 2-5 km	May entangle or detach corals during retrieval †	Low
Traps or pots	*Single-set pots*	A pot or trap that is constructed of wooden slats or coated wire mesh; set as a single pot on the bottom to harvest finfish or shellfish; pots vary in size up to 4.5 m^2	Limited spatial damage to corals during pot retrieval ‡	Low
	Longline pots	Single pots are strung together on a long line (10-90 pots)	Damages corals during pot retrieval and entanglement with lines; under certain conditions gear can be dragged like a plough on seafloor §	Medium

area of seafloor contacted per haul is relatively large, the forces on the seafloor from the trawl gear are substantial, and the spatial distribution of bottom trawling is extensive. Although not as destructive as bottom trawls and dredges, other types of fishing gear can also have detrimental effects on deep coral communities. Bottom-set gillnets, bottom-set longlines, pots and traps all contact the benthos to some degree. Vertical hook and line fishing, used in both recreational and commercial fishing, has the potential for some damage to fragile corals by the weights used, but such damage is likely to be minimal compared to other bottom-tending gear (NRC 2002; Kelley and Ikehara 2006). Chuenpagdee et al. (2003) surveyed U.S. fishery management council members (including fishers), scientists who served on the National Research Council's Ocean Studies Board or its study panels, and fishery specialists of conservation organizations, on their opinions of the ecological impacts of various classes of fishing gear. There was general agreement among respondents that unmitigated impacts to biological habitat from dredge and trawl gear were expected to be more severe than those of other gears.

Figure 1.19 Red tree corals (*Primnoa* sp.) are periodically caught with trawl gear in Alaskan waters. This specimen was caught during a NOAA Fisheries groundfish stock assessment survey in Dixon Entrance, Gulf of Alaska. Photo credit: R. Lauth, Alaska Fisheries Science Center.

Bottom Trawls and Dredges

The National Research Council (2002) concluded that bottom trawling and dredging reduce habitat complexity by removing or damaging the actual physical structure of the seafloor, and it causes changes in species composition. Stable communities of sessile, long-lived species, such as corals are especially vulnerable to acute and chronic physical disturbance (NRC 2002). Mobile bottom-tending fishing gear (trawling/dredging) reduces habitat complexity by removing structure-forming organisms that provide shelter for fishes and invertebrates (Figure 1.19). Areas of the seafloor with rough or steep bathymetry or composed mostly of bedrock and boulders are infrequently trawled due to the risk of damaged and lost gear. Such areas may support coral habitat and serve as *de facto* reserves.

Recovery of a trawled or dredged area, if allowed to occur, can take a few months to several decades, if it occurs at all, depending on the intensity and frequency of disturbances to the seafloor (Hutchings 2000). In general, there have been limited studies on the long-term impacts of trawling and dredging (FAO 2005). Recovery rates range from one to five times their generation time, depending on the life history of a particular organism (Emeis et al. 2001). In more complex habitats such as deep coral communities full recovery may require decades to centuries due to their slow growth rates (Freiwald et al. 2004).

Studies from around the world have reported severe disturbance to deep coral communities from trawling (ICES 2005). Disturbance from bottom trawling has been documented on *Solenosmilia* coral habitats on Australian seamounts (Koslow et al. 2000, 2001; Anderson and Clark 2003); gorgonian forests in New Zealand (Probert et al. 1997); off Alaska's Aleutian Islands, Alaskan primnoid habitats (Krieger 1998, 2001), corals in boulder habitats off Alaska (Freese et al. 1999), and coral gardens off Alaska (Stone 2006); *Oculina* reefs off Florida (Koenig et al. 2005); *Lophelia* reefs in the northeast Atlantic (Rogers 1999; Hall-Spencer et al. 2001; Fosså et al. 2002; Grehan et al. 2005; Wheeler et al. 2005) and Atlantic Canadian waters (Butler and Gass 2001). The distribution of *Lophelia* reefs has likely been reduced by trawling on the European continental slope (Roberts et al. 2003; ICES 2005).

Traps and pots

Disturbance to deep coral communities from single pot fishing is expected to be much less

Figure 1.20 Steel pots are used to harvest many species of crabs in Alaska. Some pots, such as this one, measure 2 x 2 x 1 m and may weigh more than 300 kg. This pot was derelict for some time and has been heavily colonized by soft corals. Photo credit: Alaska Department of Fish and Game

Figure 1.21 The black coral divers of Lahaina, Maui. Team leader Robin Lee is the diver wearing the cap. Photo credit: R. Grigg.

than that of mobile bottom-tending gear, since the extent of habitat impacted is much more limited. The potential for significant disturbance is greater if pots or traps are dragged along the bottom during retrieval (Freiwald et al. 2004; Figure 1.20). Gorgonians (*Primnoa* spp.) were reported to disappear in an area where prawn pots were set because of coral entanglement in the mesh of the pots (Risk et al. 1998). In certain fisheries, numerous traps are connected in series. These “longline pots” can cause a high level of disturbance to deep coral communities while the other types of bottom-contact gear cause moderate levels of disturbance (Table 1.2 and Chapter 2).

Demersal longlines and gillnets

High (1998) recognized that bottom contact by gillnets can alter the seafloor and that large branching corals can be detached, entangled, and brought up as bycatch by longlines. In Nova Scotia fishermen reported the snagging of gorgonian corals when longline gear became tangled (Breeze et al. 1997), and Mortensen et al. (2005) identified direct and indirect impacts of longlines on corals off Canada. Fishing gear fixed to the seafloor with anchors and weights, such as gillnets, also has the potential to impact fragile deep coral habitat, as reported off Porcupine Bank in the northeast Atlantic (Grehan et al. 2004).

Harvest

Certain deep corals have been collected or harvested for jewelry and curios since antiquity. In the U.S., commercial harvest of precious corals[4] for jewelry and curios has occurred off Hawaii periodically since 1958. In federal waters, precious corals are managed under the Precious Corals Fishery Management Plan (FMP). Implemented in 1983, this FMP regulates two distinct fisheries: one for black corals and one for all other precious corals. The Precious Corals FMP provides regulations on permits, prohibitions, seasons, quotas, closures, size restrictions, areas restrictions, including recent prohibitions on non-selective harvest.

In state waters, black and pink corals are managed under the Hawaii Administrative Rules. While black coral has been harvested in both federal and state waters for nearly five decades, harvest of precious corals (mostly *Corallium* spp.) in U.S. waters only occurred from 1966 to 1969 and from 1972 to 1979, with a short revival of the fishery in 1999 and 2000. Due to the low abundance of precious corals and their vulnerable life history traits, coral harvesting may be the single largest impact to deep corals in Hawaii. The sustainability of black coral harvests is currently of greatest concern, as populations are also being impacted by a rapidly spreading invasive coral, *Carijoa riisei* (see invasive species discussion below and Chapter 4).

In 1990 the Gulf of Mexico Fishery Management Council approved an amendment under the Coral and Coral Reefs FMP allowing harvest of up to 50,000 octocoral colonies (with the exception of sea fans) per year, for commercial trade in the aquarium industry. In Alaska, a fishery for corals was proposed but never developed, even though this region contains a variety of precious corals that are harvested in other regions.

Mineral Resource Exploration and Extraction

Oil and Gas Exploration and Production

Exploration for and production of oil and gas resources can impact deep coral communities in a variety of ways. Potential threats include the physical impact of drilling, placement of structures on the seafloor (e.g., platforms, anchors, pipelines, or cables), discharges from rock-cutting during the drilling process, and intentional or accidental well discharges

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[4] Precious corals refer to red and pink corals (family Coralliidae). The term is often used more broadly to also include black corals (family Antipathidae), gold corals (family Gerardiidae), and bamboo corals (family Isididae).

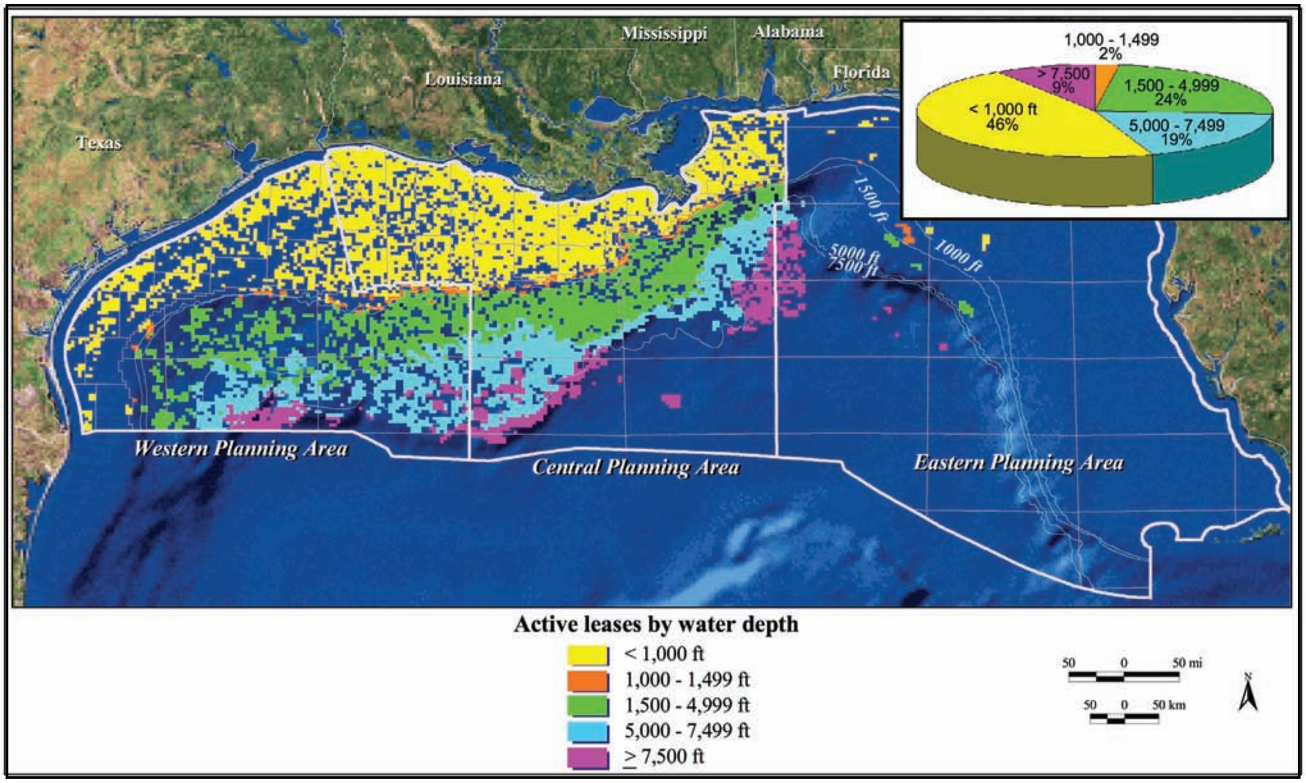

Figure 1.22 Map of the Gulf of Mexico showing active leases by water depth in 2005. Image credit: Minerals Management Service.

or release of drilling fluids. Deep-water drilling requires special synthetic-based fluids that operate at low water temperatures. These fluids are not highly toxic, but accidental release could also include oil and large amounts of sediment. While oil contains toxic fractions, a large spill of unconsolidated sediments could smother nearby corals. Smothering and death of corals by drilling muds and cuttings was observed on *Lophelia pertusa* colonies living on an oil platform in the North Sea close to drilling discharge points (Gass and Roberts 2006).

The use of anchors, pipelines, and cables for oil exploration/extraction can be destructive to sensitive benthic habitats as well. Evidence of damage from a wire anchor cable during oil and gas drilling was seen during a survey of the northeastern Gulf of Mexico, including severe damage to corals within a 1-1.5 m swath (Schroeder 2002). Cables associated with oil drilling activities have the largest potential impact on deep coral communities in the Gulf of Mexico and in some areas of the West Coast and Alaska regions. There is increasing interest in laying liquid natural gas pipelines across the East Florida shelf, and there is a potential for damage to the deep coral communities in the area.

Oil and gas exploration and production currently occur in the Gulf of Mexico, Alaska, and the West Coast regions. The spatial scale of exploration varies among these regions. Approximately 98% of all active leases occur in the Gulf of Mexico (8,140 leases; Figure 1.22) and the other 2% occur off southern California (79 leases), northern Alaska in the Arctic Ocean (~64 leases), and southern Alaska in Cook Inlet (~2 leases). In 1995, the Deep Water Royalty Relief Act allowed oil exploration and production to move into deeper waters of the Gulf of Mexico and leasing activity increased exponentially for this region. Since 2001 deep-water leasing activity has leveled off but there are still over 4,000 active leases operating in the Gulf of Mexico at depths greater than 300 m (Figure 1.22; French et al. 2005). The movement of leasing activity to deeper waters could have a significant impact on important structure-forming deep corals such as *L. pertusa*. Leases are active for five years and, while they do not necessarily lead to oil and gas extraction, they often include activities such as exploratory drilling and other activities that may be detrimental to corals.

Sand and Gravel Mining

Sand and gravel mining usually occurs within state waters in relatively shallow areas, but interactions with deep coral habitat from this industry may be more common in the future. In the past 10 years, to offset extensive beach erosion along the U.S. East Coast, 23 million cubic yards of sand was mined from the Outer Continental Shelf (OCS). While most OCS sand mining projects to date have occurred on ridges and shoals off the costs of the eastern U.S. and Gulf of Mexico (MMS 2003), 14 states (Alabama, California, Delaware, Florida, Louisiana, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, North Carolina, South Carolina, Texas, and Virginia) are working cooperatively with the Minerals Management Service (MMS) to identify sand mining sites within the OCS to replenish coastal areas in the future[5]. Sand mining activities tend to be highly localized and primarily impact soft-bottom communities.

OCS sand-mining areas do not tend to overlap with deep coral habitat because most deep structure-forming corals are found on hard-substrates. However, sand mining activities could impact sea pen groves or indirectly affect other nearby deep coral communities through an increase in sedimentation. The regions that would most likely be impacted by sand mining are the Northeast, Southeast, Gulf of Mexico, and the Central West Coast.

Seafloor Mining

Mining the deep seafloor for metals is not yet a commercially viable enterprise. Historically, interest has focused on the prospect of mining manganese nodules that are formed at abyssal depths. But other potential resources are being considered. Interests include cobalt-enriched crusts, which occur in a thin layer on the flanks of volcanic islands and seamounts at depths of 1,000 to 2,500 m – locations and depths that also include deep corals. Massive sulfide deposits on the seafloor appear to be an even more promising mining resource. These deposits contain copper, gold, zinc, and silver associated with extinct hydrothermal vents, and may yield up to 40 times the resources of land-based mines (Schrope 2007). Important deep coral communities have not been reported in association with seafloor massive sulfide deposits (ISA 2007). At least two companies have plans to begin exploration or mining in the territorial seas of other countries in the near future (Schrope 2007), but there are no current plans for mining within the U.S. EEZ. Any exploitation of mineral resources outside areas of national jurisdiction would be governed by guidelines established by the International Seabed Authority (ISA) (www.isa.org.jm). The Authority is an autonomous international organization established under the 1982 United Nations Convention on the Law of the Sea (UNCLOS) and the 1994 Agreement relating to the Implementation of Part XI of UNCLOS. Through the ISA Parties to the Convention administer mineral resources on and below the seabed in areas beyond national jurisdiction. Potential environmental impacts associated with mining cobalt-enriched crust and seafloor massive sulfide deposits were recently reviewed in an International Seabed Authority workshop (ISA 2007).

Submarine Cable/Pipeline Deployment

Deployment of gas pipelines and fiber optic cables can cause localized physical damage to deep corals. MMS regulations state that gas pipelines placed at depths greater than 61 m are not required to be anchored to the bottom or buried in the substrate. In these deeper habitats the pipelines are placed by using 12 anchors connected to a barge that are "walked" across the seabed, potentially causing damage through direct physical contact and via the swath of the anchor chains (detailed in Koenig et al. 2000). Pipelines and associated structures not anchored to the bottom may be moved around by currents and continue to damage nearby coral communities. For example, a wire anchor cable used during oil and gas drilling caused severe damage to corals within a 1-1.5 m swath area in the northeastern Gulf of Mexico (Schroeder 2002). Cable impacts associated with oil drilling activities would be most common in the Gulf of Mexico as well as some areas of the West Coast and Alaska regions. Fiber optic cables are a minimal threat to deep coral communities off the West Coast. Most of these cables are buried in the sediment, with localized impacts to deep sea communities occurring during installation, e.g., increased sedimentation, etc. (Brancato and Bowlby 2005).

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[5] More information on this program is available online at http://www.mms.gov/sandandgravel/

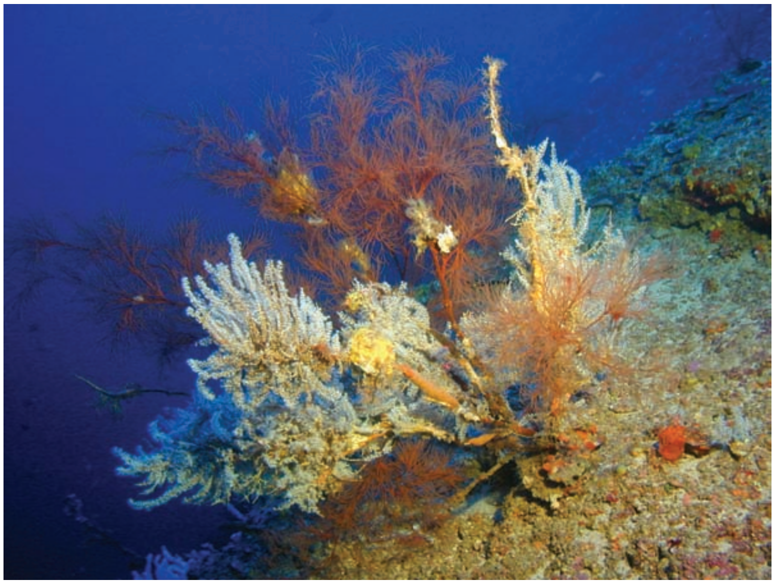

Figure 1.23 Black coral at approximately 100 m depth overgrown with the invasive snowflake coral *Carijoa riisei*. Photo credit: HURL (Hawaii Undersea Research Laboratory) archives, R. Grigg and S. Kahng.

Invasive Species

Invasions by non-indigenous marine species have increased in the United States over the past few decades due to increased shipping activities that have incidentally transported species from distant ports. The main vectors for transmission of marine invasive species are ship ballast water, hull fouling, and accidental or intentional releases of exotic species from home aquariums and scientific institutions. Because eradication programs are rarely successful, preventing the introduction of non-indigenous species should be the priority.

The invasive snowflake coral (*Carijoa riisei*; Figure 1.23) was first discovered in Pearl Harbor in 1972 on pier pilings and is believed to have arrived from the Indo-Pacific area as a hull fouling organism. The snowflake coral most often occurs in shaded areas, and has rapidly spread to deeper waters where it settles on and eventually smothers black coral colonies. In a survey of the Maui Black Coral Bed in 2001, up to 90% of the black coral colonies were dead and overgrown by the snowflake coral. This invasive coral has been found overgrowing coral colonies as deep as 120 m (Grigg 2003).

The invasive, colonial tunicate *Didemnum* sp. was recently discovered on the northern edge of Georges Bank, off New England. It is found on hard substrates, and overgrows sessile and semi-mobile epifauna (Figure 1.24). In large parts of the affected area, the tunicate covers 50% or more of the substrate. *Didemnum* sp. may be a serious threat to deep coral that occur on hard substrates in the Northeast, particularly for those corals (such as *Paragorgia* and *Primnoa)* that are known to occur on the gravel substrate of the Northeast Peak of Georges Bank. It has the potential to spread rapidly by budding and fragmentation of the mats could promote rapid range expansion.

The rates of invasions and vectors of transmission for invasive species in the deep sea are unknown. Because limited knowledge exists about the biology and ecology of deep corals in general, impacts of invasive species are difficult to measure.

Climate Change

Ocean Warming

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 to assess the risk of human-induced climate change, its potential impacts, and options for adaptation and mitigation. The IPCC 4th Assessment Report (IPCC 2007a) concluded that since 1961, the global ocean has absorbed more than 80% of the heat added to the climate system. During the period from 1961 to 2003, global ocean temperature has risen by 0.1°C from the surface to a depth of 700 m (Bindoff et al. 2007), the region where many deep corals are found.

Figure 1.24 The colonial tunicate *Didemnum* sp. advances over a pebble and cobble habitat on northern Georges Bank at a depth of 41 m Photo credit: P. Valentine and D. Blackwood, U.S. Geological Survey.

Increases in average temperature have affected waters as deep as 3000 m. Eleven of the past 12 years (1995–2006) rank among the 12 warmest years in the instrumental record of global surface temperature since 1850 (IPCC 2007a). There was significant bleaching of shallow-water corals leading to mortality during this period, especially in 1997/98 and in the Caribbean in 2005. The report concluded that it "is likely that anthropogenic forcing has contributed to the general warming observed in the upper several hundred meters of the ocean during the latter half of the 20th century" (IPCC 2007a) – i.e., as a result of the observed increase in anthropogenic greenhouse gas concentrations. These projected changes have been accompanied by observed changes in ocean salinity and biogeochemistry (Bindoff et al. 2007).

Model projections of future climate change present a number of threat scenarios. Based these scenarios the IPCC has concluded that the most likely scenario likely that the Northern Hemisphere thermohaline circulation (meridional overturning circulation) of the Atlantic Ocean will weaken during the 21st century (Joos et al. 1999; IPCC 2007a), but there is considerable decadal variability in this circulation and data do not support a coherent trend in the overturning circulation (IPCC 2007a). Thermohaline circulation is the major driving force behind currents in the deep ocean. A weakening of this process could reduce transport of food and oxygen to deep coral communities and eventually alter the structure of deep sea ecosystems. It is unclear how these changes might affect deep corals.

Ocean Acidification

The ocean acts as the largest net sink for CO_2, absorbing this gas from the atmosphere and then storing carbon in the deep ocean. Since pre-industrial times over half of the additional CO_2 attributed to human activities released in the atmosphere has been absorbed by the oceans (Sabine et al. 2004). The average pH of the ocean has decreased by 0.1 units since pre-industrial times, which represents a 30% increase in the concentration of hydrogen ions and is a geologically significant acidification of the oceans (Caldeira and Wickett 2003; IPCC 2007a). Oceanic uptake of CO_2 drives the carbonate system to lower pH and lower saturation states with respect to the carbonate minerals calcite and aragonite, the materials used to form supporting skeletal structures in many major groups of marine organisms, including corals (Kleypas et al. 2006). While the effects of ocean acidification on the marine biosphere have yet to be documented in the field (IPCC 2007b), numerous laboratory and large-scale mesocosm studies have demonstrated cause for concern. Model scenarios predict that there will be a further decrease in pH of 0.5 units by the year 2100 (Caldeira and Wickett 2005). This change in ocean chemistry could reduce the ability of corals to produce calcium carbonate skeletons (calcification) and build reefs. Others have predicted that ocean acidification as a consequence of doubling preindustrial atmospheric CO_2 could decrease shallow coral calcification rates by 10-30% (Gattuso et al. 1999; Kleypas et al. 1999; Feely and Sabine 2004). There is evidence that the rate of CO_2 increase in the deep ocean has been occurring at double the pace of shallow waters, and therefore the effect of ocean acidification on deep corals could be significant (Bates et al. 2002).

There is a natural boundary in the oceans known as the "aragonite saturation horizon" below which organisms such as stony corals cannot maintain calcium carbonate structures. As CO_2 levels increase, the aragonite saturation horizon becomes shallower, severely limiting the distribution of stony corals in certain parts of the deep sea (Royal Society 2005; Guinotte et al. 2006; Kleypas et al. 2006). Projected increases in ocean acidity could result in severe ecological changes for deep corals, and may influence the marine food chain from carbonate-based phytoplankton up to higher trophic levels (Denman et al. 2007).

Other indirect effects of ocean acidification on deep corals may involve changes in the availability of nutrients and toxins. Changes in pH could also cause a release of previously bound metals from the sediment, increasing the amount of metal toxins in the water column. There is currently a need for long-term studies on these effects *in situ* (Royal Society 2005).

Proposals have been made to capture CO_2 emissions at the time of energy production and inject it in the deep ocean, thus reducing greenhouse gas emissions into the atmosphere. Small-scale experiments and modeling suggest

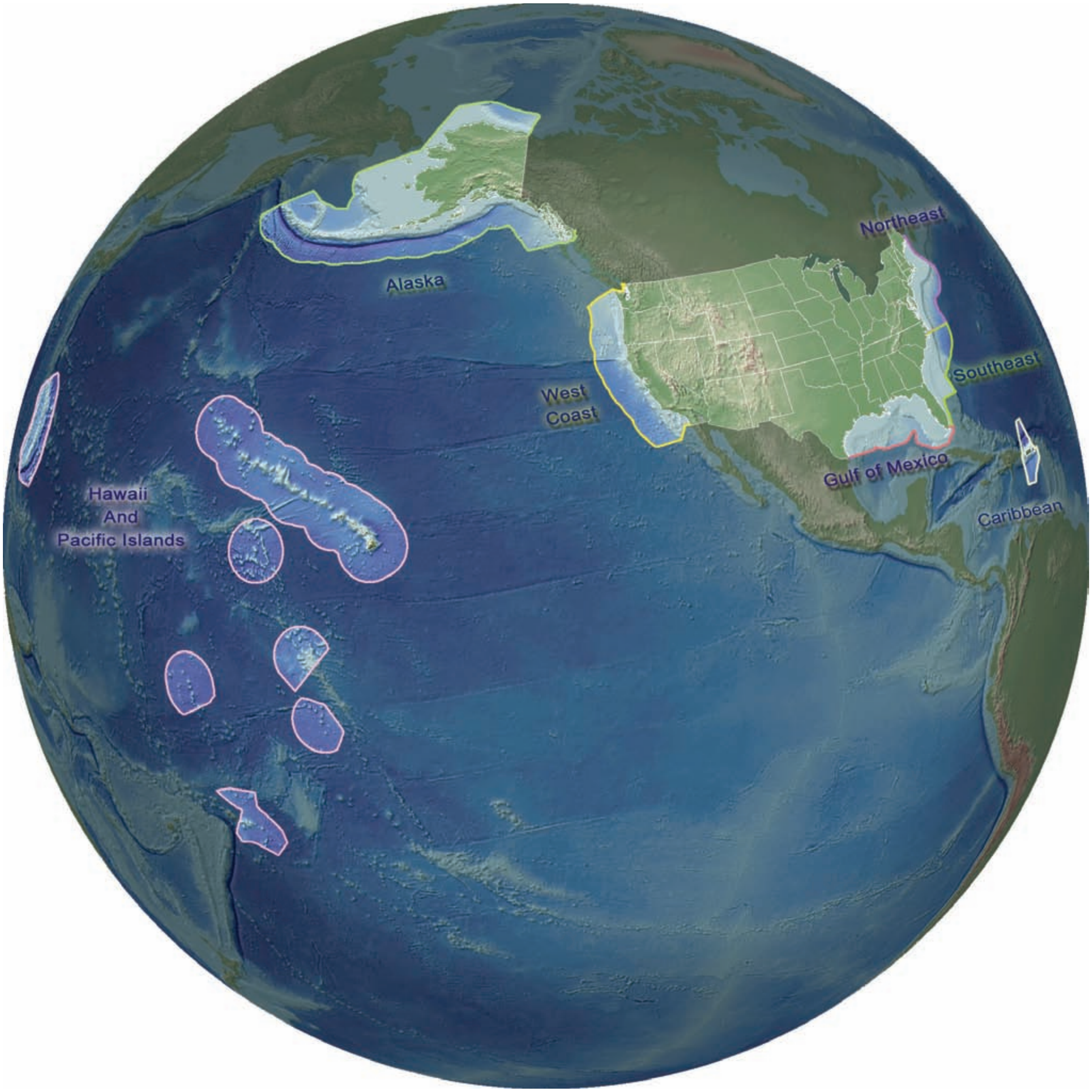

Figure 1.25 Map showing the U.S. EEZ and areas of seven regional assessments.

that injected CO_2 would be isolated from the atmosphere for several hundred years (IPCC 2005). The long term results to the atmosphere of large scale experiments are unclear, but these actions could drastically change the chemistry of the deep ocean. In the recent IPCC Special Report (2005), methods detailing carbon dioxide capture and storage were discussed. The report warned that not enough is known about the effects of excess CO_2 on benthic marine organisms. Few countries currently have legal or regulatory frameworks for dealing with environmental impacts of CO_2 sequestration.

The cumulative impacts on deep coral ecosystems of warming ocean temperatures and ocean acidification due to climate change are still unknown. They may be secondary stressors on corals already impacted by other threats or disturbances.

National Overview

In the chapters that follow, the authors draw together current knowledge, including previously unpublished data, on the distribution of deep coral communities in seven broad regions of the United States (Figure 1.25); the threats they face; and current management efforts to address these threats. The purpose of this section is to provide a brief synthesis of some of the trends found within and across the regions.

The U.S. exclusive economic zone (EEZ) extends 200 nautical miles (370 km) offshore, covering 11.7 million square kilometers in the Pacific, Atlantic, and Arctic Oceans. This broad geographic range includes a wide variety of deep-water ecosystems, most of which have not been explored. Of what is known, large regional differences exist among the types of corals present, their associated communities, the amount of available regionally specific information, and the methods applied to characterize and understand deep coral communities. The threats faced by deep coral communities differ regionally, as do the management approaches that have been adopted to address impacts from fisheries. The research and exploration work conducted over the past 20 to 30 years has helped pave the way to understanding these ecosystems and addressing management concerns, but it is only a start.

THE DISTRIBUTION OF DEEP CORAL COMMUNITIES IN U.S. WATERS

Important deep coral communities have been identified in every U.S. region. Most deep coral groups, with the exception of pennatulaceans, occur primarily on hard substrata, especially near the continental shelf break, along the continental slope, and on oceanic islands and seamounts. The distribution of individual species is determined in part by major currents, and their interaction with local geomorphology of seamounts and coastal shelves.

Currently, it is impossible to ascertain the overall extent of deep coral communities, much less their condition or conservation status in U.S. waters, because so many of the deeper areas these communities inhabit have been explored incompletely or have not been explored at all. There is also very little information on what most continental shelf habitats may have looked like before there was extensive trawling. Therefore, the following apparent trends in distribution should be viewed with caution.

Pacific

The major oceanographic influences on the U.S. Pacific Coast are the Alaska and California Currents, which are formed when the eastward-flowing North Pacific Current bifurcates near Vancouver Island. The counterclockwise Alaska Current continues along the southern edge of the Aleutian Islands as the Alaska Stream, and a parallel low salinity Alaska Coastal Current flows close to the coast from British Columbia to Unimak Pass, and into the Bering Sea. The California Current moves south, transporting cold northern waters along the Washington, Oregon, and California coasts. The northeast Pacific is characterized by a relatively narrow continental shelf with active tectonic and volcanic processes, creating a complex bathymetry of canyons and other features that support rich benthic communities. Prevailing spring and summer winds cause upwelling of deep nutrient-rich waters that influence production over the shelf.

The widespread U.S. oceanic islands and associated seamount chains in the tropical central and western Pacific are volcanic in origin and subject to various major currents. Localized flow around pinnacles, seamounts, and oceanic islands likely has the largest effect on the local abundance of deep corals. Seamounts, in any ocean basin, obstruct ocean currents and by doing so create eddies and local upwelling, form closed circulation patterns called Taylor columns, and enhance local production (Boehlert and Genin 1987). As a consequence seamounts possess both hard substrate and high flow, ideal conditions for the development of deep coral communities. The presence of seamounts and oceanic islands can have an effect on local production. In comparison to adjacent oceanic water masses, the waters around seamounts have been noted to have higher nutrient and chlorophyll concentrations, and higher zooplankton, ichthyoplankton, and micronekton biomass.

A major distinction between the North Pacific and the North Atlantic coral communities was thought to be the absence of stony coral bioherms or reefs in the deep waters of the North Pacific (Freiwald et al. 2004). Only isolated records of the stony coral *Lophelia pertusa* and other reef-builders had been reported. Stony corals accrete calcium carbonate in the form of aragonite, and accretion rates must exceed dissolution rates for reef structures to be built. Guinotte et al. (2006) noted this apparent absence of reported stony coral bioherms in the North Pacific, and hypothesized that it might reflect the shallow depth of the aragonite saturation horizon in the North Pacific (50-600 m). This horizon reaches depths of more than 2,000 m in the North Atlantic, where deep stony coral reefs have been best studied. The absence of deep coral reefs was recently called into question with the discovery of patchy, low-lying accumulations of live and dead *L. pertusa* off the coast of Washington State (Chapter 3; Hyland et al. 2005; Brancato et al. 2007). Because of the lack of massive structures in the Pacific similar to those seen in the Atlantic, it is not clear from these initial reports whether these lower-lying accumulations might be classified as reefs or bioherms.

Alaska Region: The U.S. EEZ around Alaska includes the Gulf of Alaska, Aleutian Islands, and easternBering Sea in the Pacific, and the Chukchi and Beaufort Seas in the Arctic. Deep corals are an important structural component of the first three of these Alaskan marine ecosystems (Chapter 2). Gorgonian deep corals reach their highest diversity in the Aleutian Islands, often forming structurally complex “coral gardens” with stylasterid corals, sponges, and other sedentary taxa. Gorgonians are also the most important structure-forming corals in the Gulf of Alaska, with species of the genus *Primnoa* reaching 5-7 m in size, while the Bering Sea has dense aggregations of soft corals and sea pens on the shelf and slope, respectively. The region is relatively depauperate in scleractinian corals, which occur as solitary cups and do not form true coral reefs. Most information on the distribution of deep corals comes from NOAA trawl surveys, supplemented more recently by NOAA submersible and remotely operated vehicle (ROV) studies conducted on the shelf and slope of the Aleutian Islands and Gulf of Alaska, and on seamounts in the Gulf. Currently there is very little information on deep corals in the Arctic Ocean.

The region supports some of the most important groundfish and crab fisheries in the world. It also appears to have the best-developed information on the association of fish species with many of these deep octocoral resources (Chapter 2; Heifetz 2002; Krieger and Wing 2002; Stone 2006). As some of the same coral and fish species (e.g., rockfishes) also occur along the West Coast region, it is possible that some of these fish/coral associations may also occur there.

U.S. West Coast Region: The Pacific waters off the Washington, Oregon, and California coasts are part of the California Current Large Marine Ecosystem (LME). The deep coral communities in this region are similar to those farther north along the Pacific coasts of British Columbia (Etnoyer and Morgan 2005) and Alaska (Chapter 2). As in Alaska, understanding of the spatial extent of these communities has benefited from relatively extensive NOAA trawl survey catch records, supplemented by museum collections and *in situ* observations.

Gorgonians are the most abundant and diverse structure-forming deep corals along the West Coast (Figure 1.26). As elsewhere, these appear especially associated with hard, exposed substrata and steeper slopes. There appear to be biogeographic differences in the distributions of certain deep coral groups within the region. Gorgonians appear to be most abundant south of Point Conception and north of Cape Mendocino (Chapter 3; Etnoyer and Morgan 2003). Black corals (Figure 1.27) appear abundant between Cape Mendocino and Canada.

U.S. Pacific Islands Region: The U.S. Pacific Islands represent diverse oceanic archipelagos scattered across wide areas of the Pacific and encompassing several different biogeographic regions. They do not have continental shelves or slopes, but represent emergent and non-emergent seamounts – many highly isolated from other areas. Aside from the Hawaiian Archipelago, almost nothing is known of the deep coral resources in the U.S. Pacific Islands. The first submersible explorations of American Samoa and the U.S. Line Islands were begun in 2005, and surveys of additional areas in the U.S. Pacific are needed.

Octocorals and black corals are the principal structure-forming species on deep Hawaiian slopes and seamounts (Chapter 4). Taxonomic surveys of deeper water scleractinians in Hawaiian waters have been reported by Vaughan (1907) and Cairns (1984, 2006). While the Hawaiian Archipelago shares some

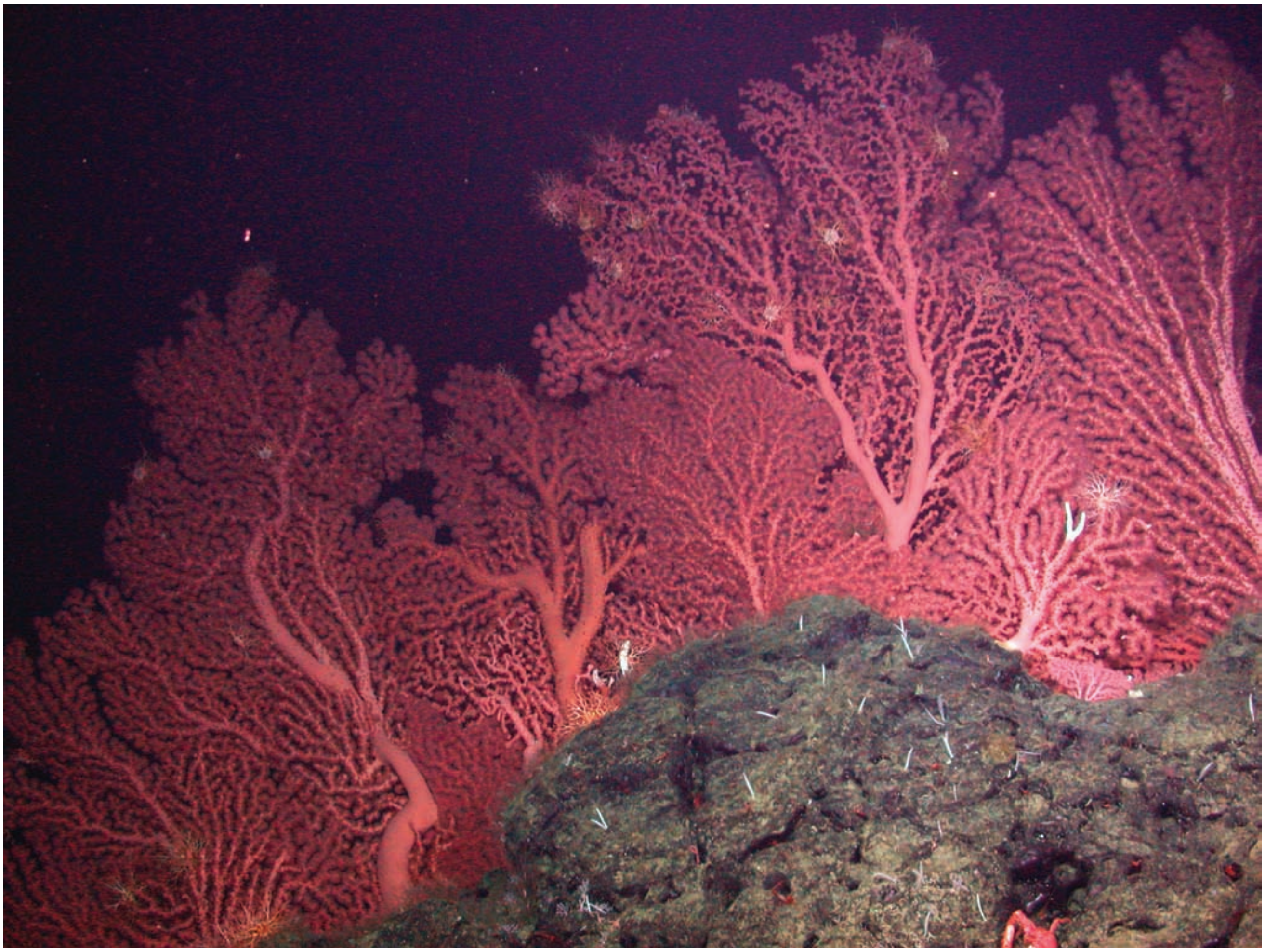

Figure 1.26 *Paragorgia* sp. crown a ridge on the Davidson Seamount. Photo credit: The Davidson Seamount Expedition, MBARI, and NOAA-OE.

species with Alaska and the West Coast, it is likely that it has a relatively high degree of endemism; rates of endemism have been estimated at 29% (Maragos et al. 2004) and 21% (Cairns 2006) for the shallow-water and deep-water scleractinian coral fauna, respectively. Paradoxically, understanding of the unique deep coral assemblages in Hawaii has benefited from information gathered in association with commercial harvests of deep corals – including gold (*Gerardia* sp.) and pink (*Corallium* spp.) precious corals and the shallower black coral (*Antipathes* spp.). Monitoring in support of management has provided perhaps the most extensive studies of growth and recruitment rates for any deep coral taxa.

Atlantic

The Gulf Stream is the dominant oceanographic feature influencing much of the U.S. Atlantic. It originates in the Caribbean, flows through a loop current in the eastern Gulf of Mexico, exits through the Florida Straits, and moves northward along the U.S. East Coast. Its depth extends to areas where it may influence deep coral distribution. Though the Gulf Stream is diverted eastward at Cape Hatteras, it still has great influence in northeast regional waters, interacting with a southwest flow of coastal waters and contributing to gyres and complex circulation patterns.

U.S. Northeast Region: The Northeast U.S. Continental Shelf Large Marine Ecosystem[6] (LME) and associated continental slope extend along the Atlantic coast from the Gulf of Maine to Cape Hatteras, with a number of seamounts occurring in the New England area. This region has among the longest histories of both deep sea scientific research and extensive trawl fisheries. Understanding of coral resources in the region has benefited from the work of Theroux and Wigley (1998) and especially Watling et al.

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[6] For more information on Large Marine Ecosystems and their designation visit www.edc.uri.edu/lme

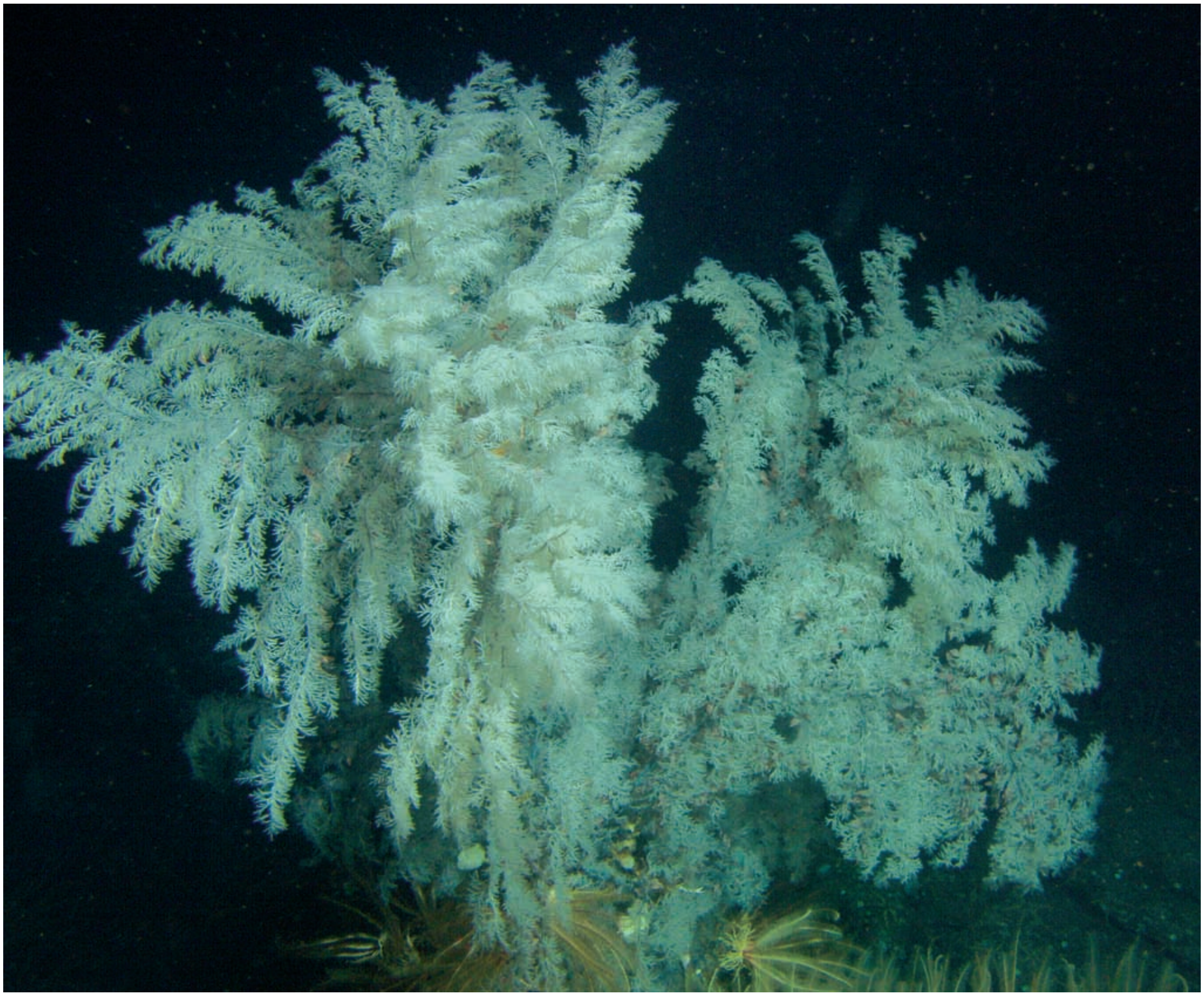

Figure 1.27 Recently discovered Christmas tree coral, *Antipathes dendrochristos*. Photographed from Delta submersible during surveys of deepwater rocky banks off southern California. Photo credit: M. Amend.

(2003) in mapping the reported occurrences of major deep coral species. Gorgonians represent the predominant structure-forming deep coral taxa in this region, and they appear to be most numerous on hard substrates associated with canyons along the shelf and Georges Bank slopes, and on the New England Seamount chain (Chapter 5; Auster et al. 2005). The principal species recorded in this region have also been recorded in Canadian waters (Gass and Willison 2005). Although *L. pertusa* has been infrequently reported from waters off the northeastern U.S., no major reef-like formations are known to exist. Such formations are common south of Cape Hatteras (Chapter 6), and known from at least one location in Atlantic Canada – the Stone Fence reef at the mouth of the Laurentian Channel (Gass and Willison 2005).

Significant concentrations of gorgonians have been recorded from Oceanographer and Lydonia Canyons on Georges Bank and from Baltimore and Norfolk Canyons further south. It is not clear, however, to what extent these reports reflect only areas where studies have been conducted. It is possible that significant additional information on coral distributions can be mined from NOAA trawl surveys conducted in this region. Recent expeditions to the New England Seamounts (Chapter 5; NOAA Ocean Exploration 2005, North Atlantic Stepping Stones) have also revealed unique assemblages of deep corals on these seamounts.

U.S. Southeast Region: Based on regions surveyed within U.S. waters, deep-water scleractinian coral reefs probably reach their greatest abundance and development in the Atlantic, south of Cape Hatteras (Chapter 6). Information from this region is primarily derived

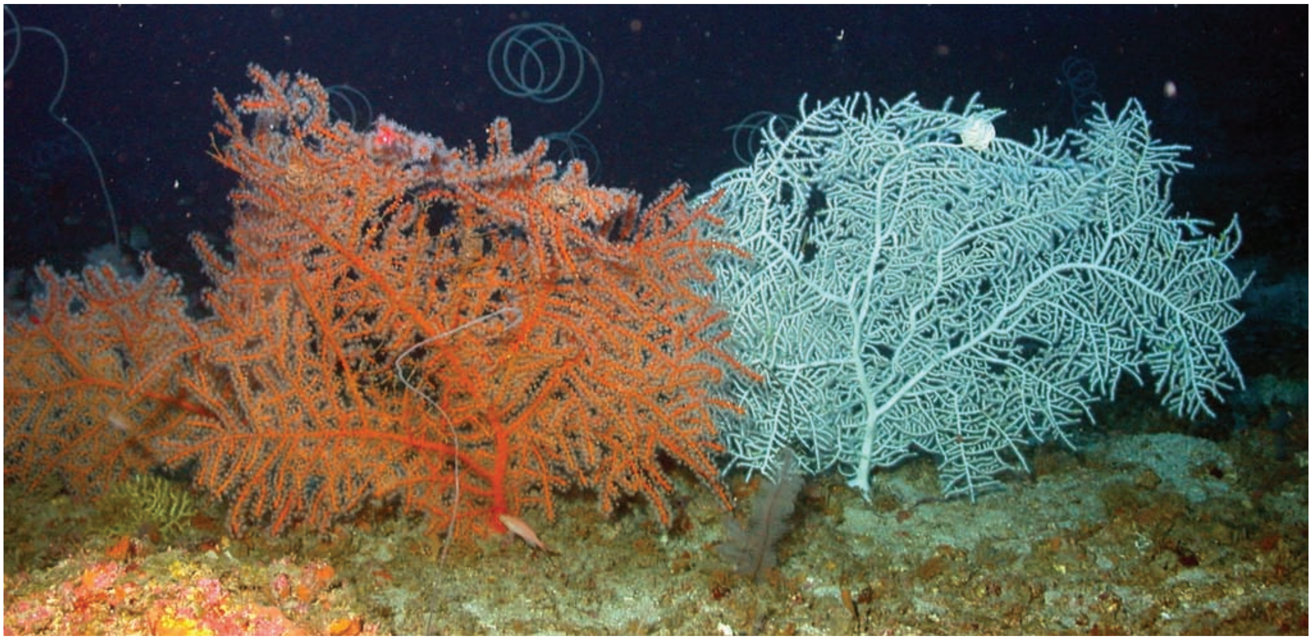

Figure 1.28 Multi-colored gorgonians with whip coral in background. East Bank, Flower Garden Banks NMS Photo credit: NURC/UNCW and NOAA/FGBNMS

from research submersible studies at isolated locations and soundings that have revealed potential coral banks. *L. pertusa* is the major structural component of reefs on the continental slope and Blake Plateau from North Carolina to Florida. It provides habitat for a well developed faunal community that appears to differ from the surrounding non-reef habitats (Chapter 6). This region is influenced by the Gulf Stream, which may contribute to biogeographic linkages between the southeast U.S. and better studied northeast Atlantic *Lophelia* ecosystems. The world's only known *Oculina varicosa* reefs are found in 70-100 m depths off east-central Florida. Because of their shallow depth, and occurrence on the continental shelf, they may differ from other deep coral reefs in structure, function, or composition of associated organisms. The shallow depth range of these reefs has facilitated a more comprehensive understanding of the ecology of the corals; the role of the reefs as essential fish habitat; and the impacts of trawl fishing on these resources (Chapter 6; Koenig 2001; Reed 2002b; Koenig et al. 2005). Gorgonians are common in the region, but in comparison to the Northeast and West Coasts, much less is known (or at least less information has been systematically collated) concerning the region's octocoral and black coral resources.

U.S. Gulf of Mexico Region: The northern Gulf of Mexico is home to major *L. pertusa* reefs, though their structure appears to differ from that observed in the southeast U.S. (Chapter 7), growing primarily on carbonate and clay substrates rather than mounds of dead coral. Despite extensive environmental studies associated with oil and gas development in the Gulf, knowledge of the distribution of deep coral reefs is limited to a handful of sites where targeted studies have been conducted. Each of the areas, from Pourtalès Terrace in the Florida Straits, to sites in the northwestern Gulf of Mexico, represent unique habitat types. As in the Southeast, little information is available concerning the distribution of gorgonian and black coral resources in this region (Figure 1.28). Cairns and Bayer (2002) identify several species of the structure-forming primnoid *Callogorgia* occurring throughout the Gulf. Of these, the endemic gorgonian *C. americana delta* is known to provide nursery habitat for catsharks (Etnoyer and Warrenchuk in press). Recent ROV surveys focused on the reefs and banks of the northwestern Gulf of Mexico at depths ranging from 50 m to 150 m have increased our knowledge of the distribution of deepwater biological communities, including antipatharians, gorgonians, and sponges (Figure 1.29). The communities are more widespread and densely populated than reported thus far. These studies are ongoing, and being led by the Flower Garden Banks National Marine Sanctuary, (E. Hickerson and G.P. Schmahl, pers. comm.).

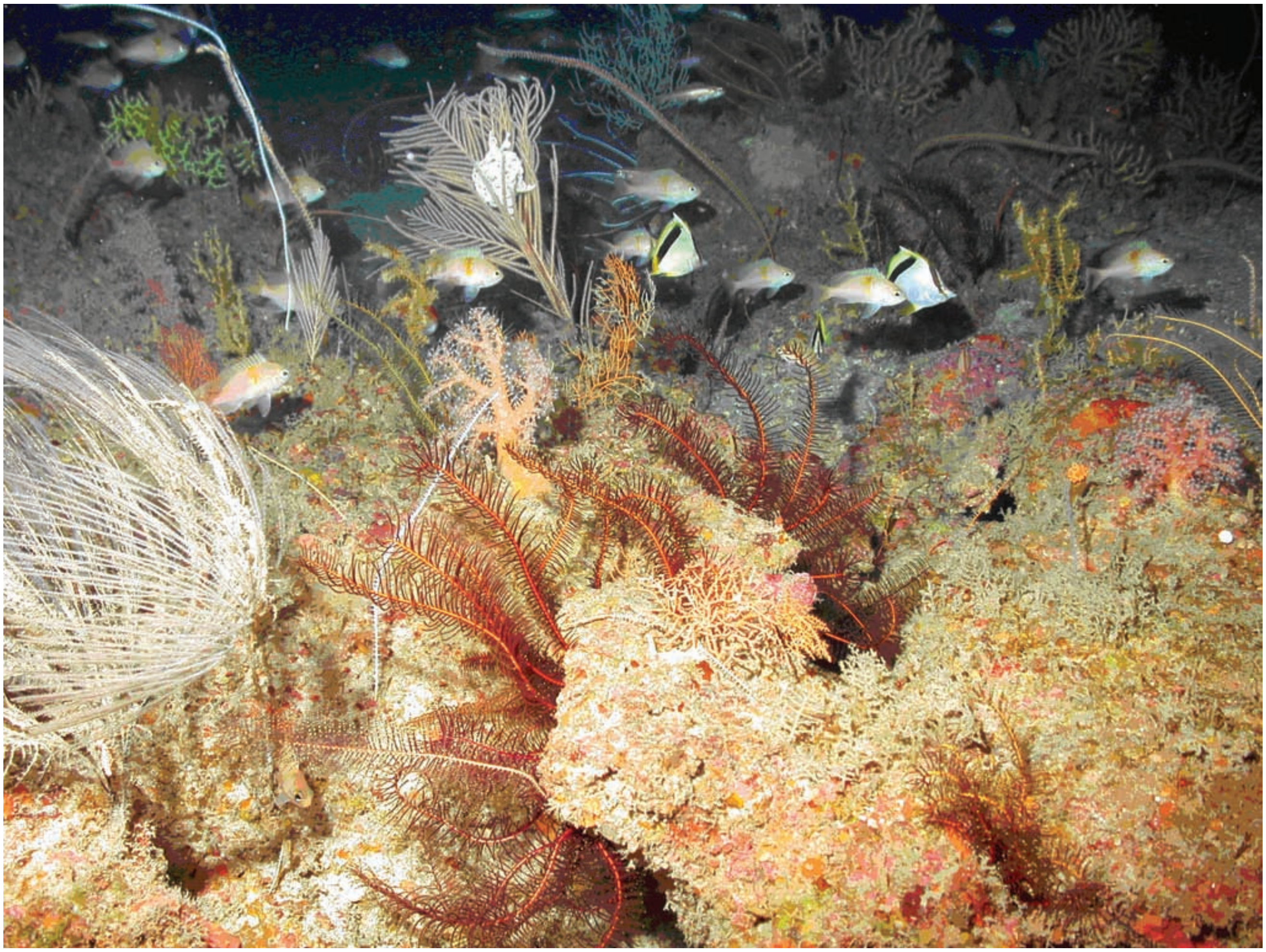

Figure 1.29 An example of deepwater habitat at the Flower Garden Banks NMS, typical of the northwest Gulf of Mexico habitats. Image includes octocorals, antipatharians, echinoderms, sponges, soft corals, and deep-water fishes. Photo credit: FGBNMS and NURC/UNCW.

U.S. Caribbean Region: The U.S. Caribbean, including the waters surrounding Puerto Rico, the U.S. Virgin Islands, and Navassa Island, represents a small part of the larger Caribbean LME. It has not been well studied with respect to deep corals, and the primary information comes from scientific collections (e.g., Cairns 1979) – most from other areas of the wider Caribbean (Chapter 8). The most extensive occurrence of deep coral mounds reported in the Caribbean is found on the northern slope of Little Bahama Bank at depths between 1,000 and 1,300 m (Chapter 8). Lithoherms have been documented in the Florida Straits, and deep coral banks are known to occur off Colombia's Caribbean shelf. There is some indication that the diversity of certain deep-water structure-forming taxa (e.g., gorgonians) may be higher in the Caribbean than in more temperate North Atlantic waters. In U.S. waters, limited ROV and submersible studies have been conducted off Navassa Island and Puerto Rico, revealing scleractinian, black, and gorgonian corals, but distributions have not been rigorously documented.

U.S. CONSERVATION AND MANAGEMENT MEASURES

Summary of Threats to Deep Coral Communities in U.S. Regions

In the chapters that follow, the authors identify key threats to deep coral communities in each region. The perceived level of each of these key threats is summarized in Table 1.3. Each region has different intensities of trawl fishing and different levels of information on the actual impacts of such fisheries. However, based on the best available data, disturbance to deep coral communities from bottom-tending fishing gear, especially bottom trawl gear, has been identified as the major concern in most regions where such fishing is allowed. Similar findings have also been reported from elsewhere around

Table 1.3. Summary of perceived levels of current threats to deep coral communities for U.S. regions. NA = Not Applicable (i.e., this threat is prohibited or does not occur anywhere within that region). Threat levels are based on the information provided by the regional chapter authors.
Note: These perceived threat levels reflect only the occurrence of these stressors in a region, and their potential, if unmitigated, to damage deep coral communities they might encounter. They do not indicate the actual impacts of each stressor, which will likely vary widely within and among regions. Since the location of deep coral habitats is incompletely known, there is uncertainty over their degree of overlap with human activities. Substantial management steps have been taken to mitigate threats. For example, significant actions to minimize adverse impacts of bottom fishing gear through gear modifications and gear closures have been taken in each region, and management procedures are in place to mitigate potential impacts of oil and gas development and mining where they occur on the outer continental shelf.

Threats	Regions						
	Alaska	West Coast	Pacific Islands	Northeast	Southeast	Gulf of Mexico	Caribbean
Bottom trawl fishing impacts	High	High	NA	High	High	Low - Medium	NA
Other bottom fishing impacts	Low - Medium	Low - Medium	Low	Low - Medium	Low - Medium	Low - Medium	Low
Deep coral harvest	NA	NA	Medium	NA	NA	NA	NA
Oil and gas development	Low	Low	NA	NA	NA	Medium	NA
Cable deployment	Low	Low	Unknown	Low	Low	Low	Unknown
Sand and gravel mining	Low	NA	NA	Low	Low	Low	NA
Invasive species	Unknown	Unknown	Medium	Unknown	Unknown	Unknown	Unknown
Climate change	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown

the world (e.g., Rogers 1999; Koslow et al. 2000; Hall-Spencer et al. 2001; Fosså et al. 2002; Roberts 2002; Grehan et al. 2005, Wheeler et al. 2005). Harvest of black and precious corals in Hawaii has been identified as a moderate threat, but it is conducted in a very selective manner, and its overall impact is minor compared to trawl fishing in other regions. Hawaii is also the only jurisdiction that has specifically identified a current threat to deep corals from an invasive species. Oil and gas exploration and development in the Gulf of Mexico, where it is increasingly moving into deeper waters, is the only non-fishing direct anthropogenic stressor that poses a moderate threat to deep coral communities. Potential impacts from climate change (Including ocean acidification) are largely unknown.

U.S. Management of Deep Coral Ecosystems in an International Context

Recent interest in deep coral ecosystems has galvanized the public and triggered conservation and management action in the United States and around the world. In recent years, conservation actions have been taken shortly after discovery of vulnerable deep coral habitats. Internationally, this includes new marine protected areas established to protect deep coral communities in the northeast and northwest Atlantic, in the Canadian Pacific, and on seamounts in Australia and New Zealand. Internationally, a series of United Nations General Assembly (UNGA) resolutions has addressed the impacts of fishing on vulnerable marine ecosystems in international waters, with specific reference to seamounts, hydrothermal vents, and cold-water corals. This international effort culminated in the December 2006 UNGA Sustainable Fisheries Resolution (A/61/105), which calls upon states and regional fisheries management organizations (RFMOs) to ensure the sustainable management of fish stocks and protection of vulnerable marine ecosystems – including seamounts, hydrothermal vents, and cold-water corals – from destructive fishing practices by December 31, 2008.

In the United States, on October 6, 2006, President Bush put forth a memorandum to promote sustainable fishing and end destructive fishing practices. This memo called upon the Departments of State and Commerce to work with other countries and international organizations to eliminate destructive fishing practices; work with RFMOs to establish regulations to promote sustainable fishing; develop new RFMOs to protect ecosystems where they do not currently exist; work with other countries to determine which vulnerable marine ecosystems might be at risk; and combat illegal, unregulated, and unreported fishing. The memorandum defines "destructive fishing practices" as "practices that destroy the long-term natural productivity of fish stocks or habitats such as seamounts, corals and sponge fields for short term gain."

In addition to addressing the effects of fishing on deep coral habitats, other multilateral environmental fora have addressed deep-sea genetic resources and the impacts of trade. All black, hydrozoan (e.g., stylasterid), and stony corals are included in Appendix II of the Convention on International Trade in Endangered Species of Fauna and Flora (CITES). These listings still allow trade under permit, but they are designed to ensure the harvest and trade is legal and non-detrimental to wild populations.

U.S. National Framework for Management of Deep Coral Ecosystems

In the U.S., management of deep coral resources has been hampered by a lack of information on the distribution, life history, and ecological role of these organisms. Deep corals were not specifically included in legislation prior to the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 (P.L. 109-479). Currently, no deep-water coral species are listed as endangered or threatened under the Endangered Species Act, nor are any presently under consideration for listing, although *O. varicosa* has been identified as a "species of concern."[7] In a number of U.S. regions, significant management measures are now being undertaken and these efforts will be discussed in the regional chapters in detail but are summarized in this National Overview. As fisheries expand into deeper waters (Roberts 2002), and oil and gas exploration and development activities move to deeper areas of the continental slope, precautionary measures should be taken to preserve the fragile biota that exist in those areas.

Most deep corals occur in the U.S. EEZ beyond the jurisdiction of individual states. Fisheries in the EEZ are managed by NOAA's National Marine Fisheries Service (NMFS) under fishery management plans (FMPs) prepared by eight regional Fishery Management Councils (FMCs) and approved by NMFS in accordance with the Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. 1801 *et seq*.). These eight Council regions align closely with the boundaries of the regional chapters in this report. As each Council region includes different fisheries and has developed FMPs independently, approaches to deep coral conservation also vary. To date, management approaches by the Councils to reduce fishery impacts on deep corals (Table 1.4) have primarily relied upon either treating the corals themselves as a managed species (South Atlantic and Western Pacific Councils) or protecting habitats identified as essential fish habitat (EFH) for managed species that may contain deep corals (South Atlantic, North Pacific, Pacific, and New England Councils). In the New England and Mid-Atlantic Council regions, where deep corals have not been specifically identified as EFH, the scope for using these provisions to protect coral habitat may be more limited. Councils are also mandated to minimize bycatch to the extent practicable, but none have used this provision directly to regulate bycatch of deep corals.

On January 12, 2007, the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 (P.L. 109-479) was enacted and included the "Deep Sea Coral Research and Technology Program." The Act calls on NOAA to: 1) identify existing research on, and known locations of, deep-sea corals and submit such information to the appropriate Councils; 2) locate and map locations of deep-sea corals and submit such information to the Councils; 3) monitor activity in locations where deep-sea corals are known or likely to occur, based on best scientific information available, including through underwater or remote sensing technologies, and submit such information to the appropriate Councils; 4) conduct research,

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[7] "Species of concern" are species about which NMFS has some concerns regarding status and threats, but for which insufficient information is available to indicate a need to list the species under the Endangered Species Act. http://www.nmfs.noaa.gov/pr/species/concern/#corals).

Table 1.4. Regional fishery management council management actions affecting deep coral habitat.

Regional Fishery Management Council	Deep Coral or Biogenic Habitat Identified as EFH for Managed Species?	Coral Management Plan?	Extensive Areas Protected from Gear Impacts?	Coral Bycatch Reasonably Well Monitored
North Pacific	Yes - Groundfish	No	Yes	Yes
Pacific	Yes - Groundfish	No	Yes	Yes
Western Pacific	No	Yes – Precious Corals	Yes	Not Applicable
New England	No	No	Limited – Lydonia & Oceanographer Canyons and New England Groundfish Habitat Closure Areas	No
Mid Atlantic	No	No	No	No
South Atlantic	Yes- Snapper Grouper Complex	Yes - Used to protect Oculina Banks	Limited - Oculina Banks HAPC	No
Gulf of Mexico	No	Yes - Not yet applied to deep coral	No	No
Caribbean	No	Yes - Not yet applied to deep corals	No	Not Applicable

including cooperative research with fishing industry participants, on deep sea corals and related species, and on survey methods; 5) develop technologies or methods designed to assist fishing industry participants in reducing interactions between fishing gear and deep-sea corals; and 6) prioritize program activities in areas where deep-sea corals are known to occur, and in areas where scientific modeling or other methods predict deep sea corals are likely to be present. The first biennial report on the progress and significant findings of the “Deep Sea Coral Research and Technology Program” is due to Congress by January 12, 2008. The Act also provides new discretionary authority for fishery management plans to designate zones where deep-sea corals are identified through the program to protect deep sea corals from physical damage from fishing gear or to prevent loss or damage to such fishing gear from interactions with deep-sea corals, after considering long-term sustainable uses of fishery resources in such areas.

In addition to the Councils, NOAA’s National Marine Sanctuary Program has responsibilities for protection and management of natural resources, and a number of sanctuaries contain deep coral resources. The goals of the National Marine Sanctuaries Act (16 U.S.C. 1431 *et seq*.) include maintaining the natural biological communities in the national marine sanctuaries, protecting, and, where appropriate, restoring, and enhancing natural habitats, populations and ecological processes. New oil and gas development is currently prohibited in all national marine sanctuaries, although leases in place before sanctuary designation (e.g., Channel Islands National Marine Sanctuary) are allowed to continue. Roughly half of the national marine sanctuaries have regulations that prohibit activities (some specific to fishing) that could damage deep coral communities. Further, a number of sites have recently taken specific actions to characterize and protect deep coral communities, in particular Flower Garden Banks, Olympic Coast, Monterey Bay and, indirectly, Channel Islands, with new marine protected area designations. These sanctuaries have been extremely active with deep coral community characterization – Monterey Bay National Marine Sanctuary at Davidson Seamount and other sites, the Flower Gardens on outer continental shelf banks of the Gulf of Mexico, and Olympic Coast in the Pacific Northwest (Figure 1.30). Deep coral communities are

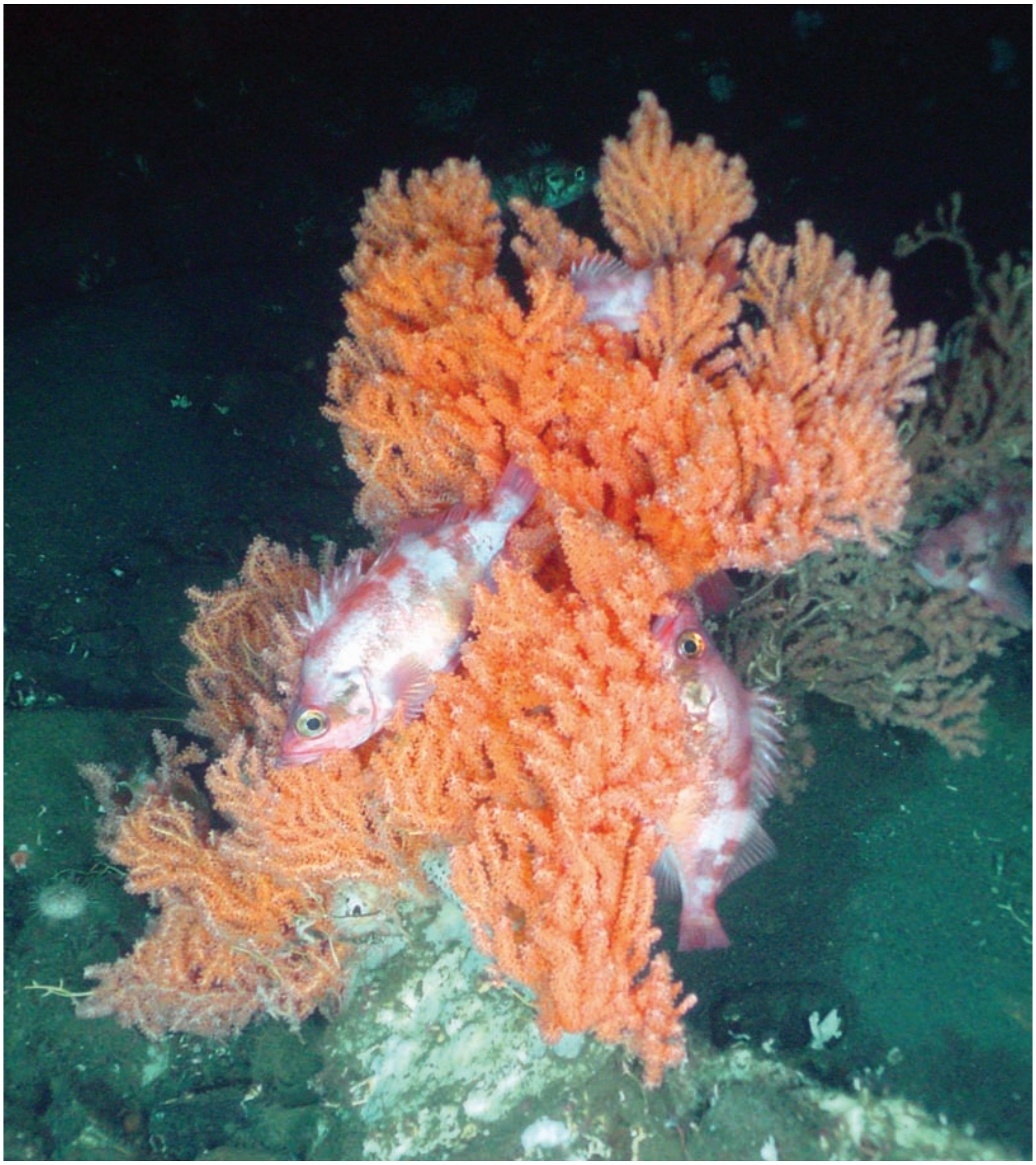

Figure 1.30 Rockfish take refuge among a primnoid octocoral in Olympic Coast National Marine Sanctuary. Photo credt: OCNMS/NOAA

found in the Papahānaumokuākea Marine National Monument (see Chapter 4). The National Marine Sanctuaries Act may provide more comprehensive protection in these areas from collecting, development, discharges, and other human activities that disturb benthic habitats. Deep coral communities may also occur in certain National Parks and National Wildlife Refuges, especially in Alaska and the Pacific remote island areas.

Mineral resource exploration and extraction activities, including oil and gas exploration in federal waters, are managed by the MMS within the U.S. Department of the Interior. The MMS regulates the impact of mineral resource activities on the environment through an Environmental Studies Program and an Environmental Assessment Program. These programs provide scientific and technical information to support decisions and monitor environmental impacts of exploration, development, and production of mineral resources. MMS established the Rigs-to-Reefs program to explore the use of decommissioned oil platforms as hard substrate for settlement and growth of corals and other sedentary marine organisms.

Regional Management Actions in the U.S. Pacific

Acknowledgement of the potential impacts of trawl and dredge fisheries to deep coral communities and other biogenic habitat has led the regional

Fishery Management Councils in the Pacific to propose historic protective measures limiting bottom-trawling in areas that might contain coral resources.

The U.S. West Coast and Alaska have an extensive history of fisheries using bottom-contact gear, including bottom trawling for Pacific cod, hake and rockfishes; bottom-set longlines for fish; and individual traps and multiple trap-lines for crab in Alaska. Alaska is currently home port to the largest fleet of U.S. bottom trawlers. The importance of these bottom-trawl fisheries has been a major factor in the development of NMFS trawl surveys. These surveys have provided the broadest scale information on the distribution and abundance of deep corals in these two regions (Chapters 2 and 3).

The North Pacific Fishery Management Council has taken a number of important steps that reduce the impact of fisheries on essential fish habitat in the EEZ around Alaska. Beginning in 1998, the Council prohibited trawling in the eastern Gulf of Alaska and southeast Alaskan waters within a 180,400 km^2 area as part of a license-limitation program. The measure was originally proposed in 1991 over conservation concerns for rockfish stocks to protect seafloor habitat from long-term disturbance from trawling. In 2000 the Council established the 10.6 km^2 Sitka Pinnacles Marine Reserve in the Gulf of Alaska and prohibited all bottom-fish gear types (except pelagic troll gear for salmon) in the reserve. These pinnacles consist of two large volcanic cones that rise to within 40 and 70 m of the ocean surface, and provide a variety of high-relief habitats colonized by the deep coral *Primnoa* sp., anemones, and other organisms. Aggregations of lingcod and several juvenile and adult rockfish species are associated with the pinnacles.

Recently, the North Pacific and Pacific Fishery Management Councils each took historic steps, recommending to “freeze the footprint” of bottom-trawling within their respective jurisdictions in order to protect EFH. In 2006, NMFS approved a number of North Pacific Council recommended EFH closures in the Aleutian Islands and Gulf of Alaska. Many of these areas are known to contain important deep coral and sponge habitats. More than 950,000 km^2 along the remote Aleutian Islands were closed to bottom trawling – targeting areas that had not yet received extensive trawling, with 377 km^2 of “coral gardens” closed to all bottom-tending fishing gear. Additionally, 7,155 km^2 in Gulf of Alaska Slope Habitat Conservation Areas were closed to bottom trawling and 18,278 km^2 of Alaska seamounts and 46 km^2 of *Primnoa* coral areas in the Gulf of Alaska were closed to all bottom-tending fishing gear. In June 2007, the North Pacific Fishery Management Council adopted additional measures to conserve benthic fish habitat in the Bering Sea. These measures, if approved, NMFS would prohibit bottom trawling over an additional area of more than 450,000 km^2.

The Pacific Fishery Management Council is responsible for developing FMPs for fisheries off the coasts of California, Oregon, and Washington. Within the past three to six years, commercial fishing has been prohibited or significantly curtailed within the Cowcod and Rockfish Conservation Areas. While these restrictions were not designed to address impacts on deep corals, they are likely to protect some deep coral habitats. Beginning in 2000, the Council also prohibited footrope trawls (footrope=weighted edge of trawl that impacts seafloor) greater than 8 inches on most of the continental shelf, effectively making many complex, rocky habitats that are home to deep corals inaccessible to trawlers.

In 2006, NMFS approved a plan that identified and described EFH for Pacific groundfish and prohibited bottom trawling in 336,700 km^2 of habitat off the West Coast of the U.S. This represents over 42 percent of the EEZ off Washington, Oregon, and California, including areas that may contain deep coral and sponge habitats. Selected areas with known deep coral resources (e.g., Davidson Seamount) are protected from all bottom-contact gear.

Unlike most other areas of the United States, the Insular Pacific has no history of domestic bottom-trawl fisheries. The Western Pacific Fishery Management Council manages the fisheries in federal waters around the Territory of American Samoa, Territory of Guam, State of Hawaii, Commonwealth of the Northern Mariana Islands, and other U.S. Pacific island possessions. It has the oldest and most comprehensive restrictions designed to protect coral and other biogenic habitat from adverse impacts of fishing gear.

In 1983, the Council prohibited the use of trawl gear, bottom-set longlines, and bottom-set gillnets - all identified as threats to deep corals - within all waters in their region of the U.S. EEZ. This action was taken, in part, in response to observed impacts of foreign trawl fisheries on seamounts (e.g., Hancock Seamount) before the declaration of the U.S. EEZ.

In 1983, the Western Pacific Fishery Management Council also developed a Precious Corals FMP. The coral beds included in the FMP contain several deep coral species (Chapter 4). Under the 1983 FMP and its amendments, NMFS established quotas and minimum legal sizes for harvest of pink, black, gold, and bamboo coral, and, in 2002, prohibited the use of non-selective gear. Currently, only the black coral fishery within Hawaii State waters is active, and the Council and State are in the process of revising management plans that incorporate the recent impacts of the invasive soft coral *Carijoa riisei*.

Regional Management Actions in the U.S. Atlantic

The Northeast U.S. region has the longest history of major trawl and scallop dredge fisheries in the United States and its bottom-trawl fishery is second in size only to Alaska's. As a result, much of the continental shelf has been heavily trawled or dredged. In addition to trawling, there are active fisheries using bottom-set longlines, gillnets, and pots and traps, some extending into the slope and canyon habitats that are known deep coral habitat.

The New England Fishery Management Council manages fisheries off the coast of Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut. The Mid-Atlantic Fishery Management Council is responsible for management of fisheries in federal waters off the coasts of New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, and North Carolina.

The two Councils oversee significant trawl and dredge fisheries with potential impacts on deep coral habitats. In 2005, in order to minimize adverse impacts to EFH, NMFS approved Council-recommended closures of Oceanographer and Lydonia Canyons (approximately 400 km^2, on the southern flank of Georges Bank), to bottom trawling and gillnetting for monkfish. These canyons are areas of known deep coral communities. Also approved were limits on the size of the bottom-trawling roller gear and rockhopper gear on the footrope of the nets to no more than six inches in diameter in the submarine canyon areas off the shores of the mid-Atlantic states known as the "southern management area" of the monkfish fishery. In

The South Atlantic Fishery Management Council has jurisdiction over FMPs in the EEZ off North Carolina, South Carolina, Georgia, and eastern Florida to Key West (note: North Carolina is represented in both the Mid-Atlantic and South Atlantic Councils). Trawling in the south Atlantic region is primarily limited to shrimp trawling on the continental shelf. The Council was an early leader in addressing the threats of bottom trawling to deep coral communities. In 1984, the Council established the 315 km^2 *Oculina* HAPC, the world's first protection granted specifically to a deep coral habitat. In 2000 the South Atlantic Council expanded the *Oculina* HAPC to 1,043 km^2. The South Atlantic Council is currently reviewing and evaluating options for gear regulations and four new HAPCs containing deep coral habitats, including two very large areas, as part of a Comprehensive Fishery Ecosystem Plan Amendment (Chapter 6).

The relatively shallow nature of the *Oculina* coral banks probably led to their early recognition as important habitats to conserve. Unfortunately, they have also been more accessible to trawlers (primarily rock shrimp and calico scallop). Despite early protection, enforcement difficulties resulted in continued destruction through illegal fisheries until recent requirements for use of vessel monitoring systems and enhanced enforcement. Koenig et al. (2005) estimated that 90% of *Oculina* coral banks had been damaged by trawling by 2001 and only 10% remained intact. This is perhaps the clearest U.S. example of the extensive damage to deep coral communities by trawling. *Oculina varicosa* was identified by NMFS in 1991 as a "candidate species" for potential listing under the Endangered Species Act, based on well-documented declines in the *Oculina* coral banks areas due to damage from mechanical fishing gear, coupled with a lack of observed recruitment. In 2000 this designation was revised to "species of concern."

In addition to addressing fishing impacts, the State of Florida has been proactive in the management of potential new threats. Liquid natural gas ports and pipelines are being proposed that could impact deep coral habitats. Florida is also a major hub for fiber optic cable connections throughout the Caribbean. The State of Florida has been a leader in developing incentives for companies to locate cables in less environmentally sensitive corridors.

In the central and western areas of the U.S. Gulf of Mexico, concerns over potential damage from fisheries are overshadowed by issues of oil and gas exploration and development. With over 4,000 active leases in depths inhabited by *Lophelia* coral (deeper than 300 m), there is potential for adverse interactions. A strategy, developed in 2003 to address post-lease National Environmental Policy Act compliance in deeper waters (>400 m), requires lessees and operators to submit an exploration plan for an ROV survey of well sites. The plan requires a visual survey of the seafloor in the vicinity of the well before and then immediately after drilling activities to ensure that drilling activities do not have impacts on local benthic fauna. Almost half of the deep-water lease sites have been thoroughly surveyed with ROVs to document the biological communities found in these areas (MMS 2003). Along the continental shelf of the northwestern Gulf of Mexico, dozens of reefs and banks harbor deepwater communities of antipatharians, gorgonians, and sponges, in depths from 50 m to 150 m. The MMS has provided protection from direct impacts from oil and gas activities through the topographic features stipulation, which places “no-activity” zones and other regulatory zones around these biologically sensitive areas. These zones will be re-evaluated based on newly acquired bathymetry.

The Gulf of Mexico Fishery Management Council has jurisdiction over FMPs in the federal waters off Texas, Louisiana, Mississippi, Alabama, and the west coast of Florida. The primary fishing impacts of concern to deep corals in the Gulf of Mexico revolve around limited deep-water trawl fisheries for royal red shrimp. The Council has a Coral FMP and has protected several shallow-water coral banks, but has not yet identified deep coral habitat areas of particular concern. Fishing restrictions through the Coral EFH of the HAPC designation prohibit bottom longlining, bottom trawling, buoy gear, dredge, pot, or trap and bottom anchoring by fishing vessels at West and East Flower Garden Banks, Stetson Bank, McGrail Bank, and an area of Pulley’s Ridge. Other NW GOM HAPC’s that do not carry any regulations are in place at 29 Fathom, MacNeil, Rezak, Sidner, Rankin, Bright, Geyer, Bouma, Sonnier, Alderdice, and Jakkula Banks. The Council recently asked its Coral Scientific and Statistical Committee to develop a research approach to identify locations of deep corals in the Gulf.

Although not expressly prohibited, there is no history of trawl fisheries in the U.S. Caribbean. Fish traps are commonly used in shallower waters, but deeper areas are not targeted. The Caribbean Fishery Management Council has jurisdiction over FMPs in federal waters surrounding the Commonwealth of Puerto Rico and the United States Virgin Islands. The Caribbean Council has a Corals and Reef Associated Invertebrates FMP, but, like the Gulf of Mexico Council, it has not proposed management measures that would specifically identify deep coral areas. Navassa Island, claimed by both the United States and Haiti, is administered by the United States Fish and Wildlife Service, which manages the Navassa Island National Wildlife Refuge.

DEEP CORAL INFORMATION NEEDS AND RESEARCH PRIORITIES

The authors of each of the regional chapters have identified research priorities for their region. The following research priorities are common to several or all regions, or areas of research that transcend regional interests and boundaries and would contribute directly to improved management. Most of these priorities address information related to identifying locations of deep coral communities and the status and trends of deep corals and their associated communities, and do not represent a comprehensive list of scientific research needs (see also McDonough and Puglise 2003; Puglise et al. 2005). *In situ* research on deep coral communities requires the use of specialized types of underwater technology.

Habitat Mapping and Characterization

The highest priority in every region is to locate, map, characterize, and conduct a baseline assessment of deep coral habitats. The location of deep coral habitats is not well known, making it difficult if not impossible to adequately protect these habitats and manage associated resources. Acoustic multibeam bathymetry maps and associated backscatter imagery at depths between 200 and 2,000 m on continental slopes and seamounts are basic tools for determining the potential distribution of deep coral communities. Bathymetric maps of underwater topography can identify areas of potential coral habitat, based on slope or other physical features (Morgan et al. 2006), which can then be prioritized for more detailed study. Multibeam backscatter imagery provides clues as to substrate hardness. With the exception of sea pens (pennatulaceans), the major structure-forming deep corals are dependent upon exposed hard substrata for attachment. Though in certain cases larger deep coral reef formations have been successfully identified from multibeam imagery (Roberts et al. 2005), the low resolution of surface-mounted sonar will hinder efforts to identify some coral habitats using this technology alone.

The Gulf of Mexico, Pacific coast, and Alaskan regions have the most extensive multibeam mapping information. Much of the mapping in the Gulf of Mexico and the West Coast regions was conducted as part of oil and gas exploration activities, while mapping in Alaska has been undertaken primarily in association with biological studies or for navigational purposes. Recently, some deeper water areas around the Main and Northwestern Hawaiian Islands, American Samoa, and other U.S. Pacific territories have been mapped (Chapter 4; Miller et al. 2003) by NOAA. Likewise, important mapping efforts are underway in the Gulf of Maine on the northeast U.S. shelf. In this region, anticipated multibeam mapping of the continental slope and canyons will reveal bottom topography and substrates most likely to support corals, thus allowing more efficient and directed sampling efforts. A comprehensive effort to use existing habitat maps to predict the location of deep coral habitats has not yet occurred in any region.

As noted above, the South Atlantic Bight has the most extensive deep coral reefs known to date in U.S. waters. However, with the exception of the relatively shallow *Oculina* banks (Figure 1.31), there is no synoptic multibeam bathymetry and backscatter imagery for the shelf break, slope, and Blake Plateau. Given the unique character of these deep reef habitats and the potential for identifying coral bioherms, this region is among the priorities for mapping. Limited mapping in this region was conducted in 2007. Since National Marine Sanctuaries also have the authority and responsibility to preserve deep coral communities within their boundaries, mapping, and characterizing deep coral communities in the sanctuaries is a priority.

In addition to broad-scale habitat mapping efforts,

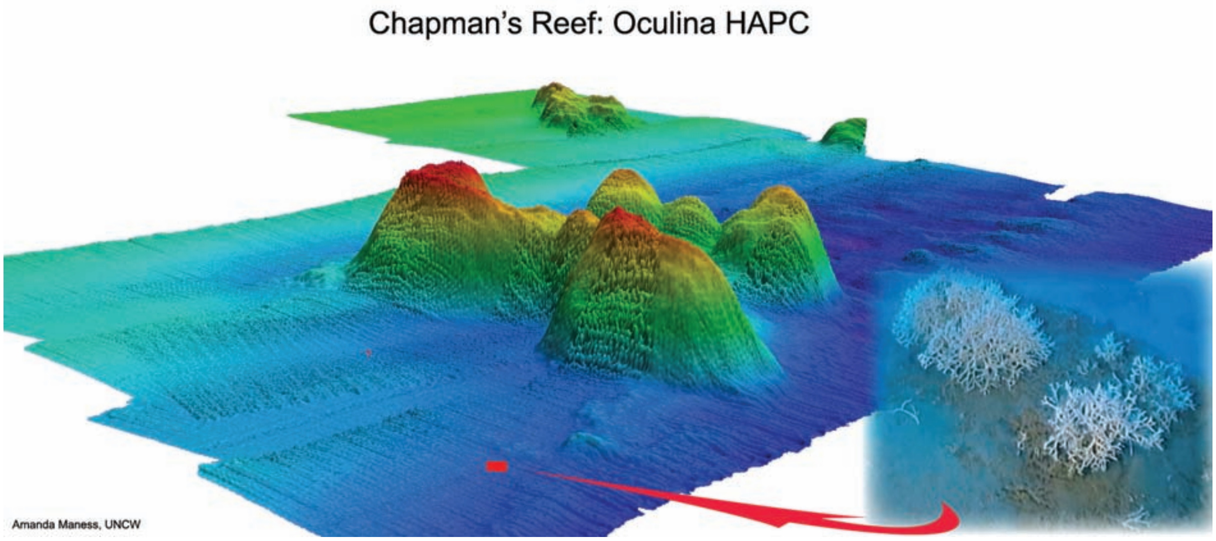

Figure 1.31 3-D colored bathymetry of Chapman's Reef, from 2005 survey done with multibeam sonar from R/V *Cape Fear* by Seafloor Systems, Inc. Image credit: A. Maness.

focused fine-scale mapping of known deep coral areas is needed, using side-scan sonar and *in situ* ground-truthing (e.g., submersibles or ROVs). State-of-the-art technologies, such as autonomous underwater vehicles (AUVs) and laser-line scan also show promise for finer scale mapping and habitat characterization.

Modeling the Distribution of Deep Coral Habitats

Even with detailed multibeam maps of the seafloor, researchers, and managers will still be severely limited by the high costs of ground-truthing potential deep coral areas. Therefore, alternative techniques for targeting finer-scale studies will be needed. One promising approach involves modeling coral habitat requirements coupled with validation from *in situ* observations. Factors to be modeled may include substrate type, seafloor geomorphology, hydrography, nutrient levels, and water temperature (Freiwald et al. 2004). For example, Leverette and Metaxas (2005) used predictive models to identify suitable habitat for *Paragorgia arborea* and *Primnoa resedaeformis*, two major structure-forming gorgonians in the Canadian Atlantic continental shelf and slope. Modeling the distribution of deep coral habitats will greatly facilitate focusing future research efforts geographically and to identify areas where a precautionary management approach is warranted until ground-truthed data can be collected. The accuracy and efficacy of such models is dependent on the quality of data inputs and consequently this approach is still dependent, to some degree, on costly collection techniques.

Data Mining and Data Management

Identification of new deep coral areas will continue to depend upon visual ground-truthing in addition to acoustic mapping and modeling. Because of the cost of new exploratory surveys, there is a high priority to "mine" data from museum collections or past submersible surveys focused on other subjects (e.g., geology or fish) to yield distributional data for corals at a low cost. Some of these (e.g., video transects) may also provide qualitative baselines for assessing change. NMFS has been conducting trawl surveys since its inception in the 1970's and much could be learned from this existing data source. A new Southeastern Area Deep Sea Coral initiative has begun to systematically document the distribution of deep corals in the South Atlantic Bight based on existing data collected during NOAA-sponsored submersible and ROV operations.

There is also a need to better manage existing information to enhance research collaboration and access to data for management purposes. The South Atlantic Fishery Management Council, in coordination with the Florida Wildlife Research Institute and NOAA, has experimented with web-accessible data models to combine deep coral data and other ecosystem information for the Southeast U.S. region. NOAA is collaborating with the U.S. Geological Survey and the United Nations Environment Programme's World Conservation Monitoring Centre in new deep coral database efforts. NOAA's Coral Reef Information System (CoRIS), primarily dedicated to serving shallow-water coral reef data and information, currently contains deep coral information submitted on an ad hoc basis, but has indicated its interest in expanding efforts to serve deep coral data.

Monitoring

Monitoring is key to understanding the state of resources and gaining clues to processes that may effect change. The United States identified the development and implementation of a nationally coordinated, long-term program to monitor shallow-water tropical reefs as a key conservation objective (USCRTF 2000). In contrast to shallow reefs, where a national coral reef monitoring network is taking shape (Waddell 2005), the costs associated with assessment and monitoring in the deep sea are much higher. As a result, it is likely that many deep coral communities remain to be discovered, baseline data are limited for most known occurrences, and quantitative repeated measures are largely absent.

To date, monitoring of deeo croals in U.S. waters has been limited to select locations off Hawaii and the southeast U.S. In Hawaii, monitoring has concentrated on species targeted for harvest (primarily black and pink corals), but has yielded valuable life history and ecological information on these corals (Chapter 4). An infestation of the invasive snowflake coral, *Carijoa riisei*, was also incidentally discovered during monitoring efforts and is now a major factor shaping recent management and harvest decisions. Systematic monitoring of the *Oculina* Banks Experimental Research Reserve, a 315 km^2 subset of the 1,043 km^2 *Oculina* Bank HAPC, was initiated in 2005. Between 1994 (when all fishing for snapper and grouper species was prohibited in the Reserve) and 2004, 56 ROV dives and 15 research submersible dives had explored only 0.11% of the HAPC. In 2005, regular observations on baseline transects at the same sites in protected and recently discovered unprotected banks were initiated (M. Miller pers. comm.). Although it is too early to assess the success of this approach, this appears to be the first effort to systematically monitor a deep coral reef ecosystem. The South Atlantic Fishery Management Council developed an *Oculina* Research and Evaluation Plan (http://ocean.floridamarine.org), but funding for follow-on monitoring has not been identified.

Taxonomy, Biology, and Life History of Deep Coral Species

Despite recent advances in the study of deep coral taxa, much of their basic life history and biology is still unknown. Worldwide, the greatest emphasis has been placed on studying the few species of stony corals, such as *Lophelia pertusa*, that form deep reef-like structures. In U.S. waters outside the Southeast and Gulf of Mexico, the most abundant and important structure-forming corals are the gorgonians, with hydrocorals, black corals, and pennatulaceans providing significant habitat complexity in certain regions. The basic taxonomy of these deep coral taxa, their biogeography, and processes that may contribute to distributions and endemism are poorly known. Genetic studies of key structure-forming species can contribute to understanding both taxonomic relationships and connectivity among populations. The latter can provide information to determine larval source-sink patterns and gene flow between deep coral populations and is key to understanding recruitment dynamics.

Basic life history and ecological studies are needed to contribute to understanding the population biology, changes in abundance over time, and factors affecting the resilience of deep corals to disturbance. These studies include factors influencing reproduction, recruitment, and recolonization rates, as well as patterns and processes of growth and mortality for key coral species.

Biodiversity and Ecology of Deep Coral Communities

Structure-forming deep corals have been shown to provide important ecosystem functions in the deep-sea environment – especially as habitat for numerous other species. With the exception of *Oculina* reefs off Florida, the biodiversity of these communities in U.S. waters has not been quantitatively assessed, and functional relationships between the corals and associated species are incompletely understood. In addition to species inventories and quantifying the associations between corals, other invertebrates, and fish, studies are needed to characterize trophic dynamics within deep coral communities and the life history of associated species.

Understanding the ecological function of these communities, including their role in mediating patterns of biodiversity and their importance as habitat for federally managed species, is a management priority. Designation and subsequent protection of HAPCs in the United States depends on a demonstrated linkage between a federally managed fish species and deep corals or other associated habitat features - i.e., demonstration that these features represent EFH as defined by the Magnuson-Stevens Act. When the Act was reauthorized in 2006, Councils received additional discretionary authority to designate zones other than EFH for the protection of deep-sea corals. Under the National Marine Sanctuaries Act, deep corals can be preserved for their intrinsic value as sensitive and important components of the ecosystems within the sanctuaries.

Effects of Climate Change and Ocean Acidification

Deep corals may provide windows into past environmental conditions in the deep ocean, as well as clues for prospective analyses of future changes that may result from climate change. A growing number of researchers are looking at isotopic proxies for past temperature or other environmental conditions over decades in long-lived gorgonians and over geologic timescales in stony coral reef mounds (Smith et al. 1999; Risk et al. 2002; Williams et al. 2006).

Deep coral communities are vulnerable to changes in ocean chemistry associated with increased atmospheric CO_2 from the combustion of fossil fuels (Guinotte et al. 2006). There have been no studies on the sensitivity of deep corals to CO_2-associated ocean acidification, but potentially calcification rates, especially of stony corals such as *Lophelia* will decrease, and conditions in vast areas of the ocean may become unsuitable for deep reef accretion (Royal Society 2005).

Fishery Impacts

From a management perspective, filling information gaps on human activities that may impact deep coral communities is a critical need. Because fishing impacts are currently the major threat to these communities in U.S. waters and around the world, it is especially important to gain a comprehensive understanding of fishing effort and distribution. Coral bycatch in fisheries and stock assessments have proven especially valuable in mapping coral resources and interactions with fisheries in Alaska and the West Coast (Chapters 2 and 3). NOAA's long-standing trawl surveys and observer programs in the Northeast are well positioned to include these types of observations and analyses. The Southeast Region, in both the southeast U.S. and the Gulf of Mexico, currently needs improved reporting and mapping of fishing effort, as well as increased observer coverage, reporting, and analysis of coral bycatch.

Other Anthropogenic Stressors

A number of other localized anthropogenic impacts, such as those associated with oil and gas exploration and development and with cable and pipeline deployment, have been reported in deep coral habitats within U.S. waters. Because the extent and impacts of these stressors to deep coral communities is incompletely documented, there is a need is to characterize the spatial distribution of these impacts and their ecological consequences. Once this information is well understood, management plans may be implemented to relocate these activities to areas where deep coral communities are not threatened.

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Appendix 1.1. This table represents a compilation of the major structure-forming deep coral species found within the U.S. EEZ in one or more of the Pacific regions. The species were identified by regional authors based on one or more criteria including abundance, size (>15 cm), and associations with other invertebrates. ● Corals identified by regional authors as major structure-forming species, ○ Coral species occurring in region but not identified by regional author as major structure-forming. * Coral genus with a species not identified or not specified - may represent different species in the genus in a different region

Higher Taxon	Species	Alaska	West Coast	Pacific Islands
Phylum Cnidaria				
Class Anthozoa				
Subclass Hexacorallia				
Order Scleractinia				
Family Caryophylliidae	*Lophelia pertusa*		●	
Family Dendrophylliidae	*Enallopsammia rostrata*			●
	Dendrophyllia oldroydae		●	
Family Oculinidae	*Oculina profunda*		●	
Order Antipatharia				
Family Antipathidae	*Antipathes dendrochristos*		●	
	Antipathes spp.*			●
Family Cladopathidae	*Chrysopathes formosa*	●	○	
	Chrysopathes speciosa	●	○	
Family Schizopathidae	*Bathypathes patula*	●		○
	Bathypathes sp.		●	
	Dendrobathypathes boutillieri	●		
Order Zoanthidea				
Family Gerardiidae	*Gerardia* sp.			●
Subclass Octocorallia				
Order Alcyonacea				
Family Neptheidae	*Eunephthea rubiformis*	●	○	
Order Gorgonacea				
Family Coralliidae	*Corallium secundum*			●
	Corallium laauense			●
Family Isididae	*Isidella* spp.*	●	●	●
	Keratoisis profunda	●		
	Keratoisis sp.*	○	●	○
	Lepidisis sp.*	●	○	○
Family Paragorgiidae	*Paragorgia arborea*	●	●	
	Paragorgia sp.*	○		
Family Primnoidae	*Fanellia* sp.*	●		○

Higher Taxon	Species	Alaska	West Coast	Hawaii
	Plumarella sp.*	●	○	○
	Primnoa pacifica	●	●	
Order Pennatulacea				
Family Anthoptilidae	*Anthoptilum* spp.	●	○	○
Family Halipteridae	*Halipteris willimoesi*	●		○
Family Protoptilidae	*Protoptilum* sp.	●		
Class Hydrozoa				
Order Anthoathecatae				
Family Stylasteridae	*Stylaster cancellatus*	●		
	Stylaster campylecus	●		

Appendix 1.2. This table represents a compilation of the major structure-forming deep coral species found within the U.S. EEZ in one or more of the Atlantic regions. The species were identified by regional authors based on one or more criteria including abundance, size (>15 cm), and associations with other invertebrates. ● Corals identified by regional authors as major structure-forming species, ○ Coral species occurring in region but not identified by regional author as major structure-forming species. Deep-water corals reported by a circle under "Caribbean" heading are from the U.S. Caribbean only. ~ Indicate strcuture forming coral found in Caribbean but not in U.S. waters.

Higher Taxon	Species	Northeast	Southeast	Gulf of Mexico	Caribbean
Phylum Cnidaria					
Class Anthozoa					
Subclass Hexacorallia					
Order Scleractinia					
Family Caryophylliidae	*Lophelia pertusa*	○	●	●	●
	Solenosmilia variabilis	○	○	●	~
	Desmophyllum dianthus	○	○	○	●
Family Dendrophylliidae	*Enallopsammia profunda*	○	●	●	~
	Enallopsammia rostrata	○	○		●
	Dendrophyllia alternata			○	~
Family Oculinidae	*Madrepora oculata*		●	●	●
	Madrepora carolina		○	●	●
	Oculina varicosa		●	○	~
Family Pocilloporidae	*Madracis myriaster*		●	○	●
Order Antipatharia					
Family Antipathidae	*Antipathes americana*				●
	Antipathes caribbeana				●
Family Leiopathidae	*Leiopathes glaberrima*		●	●	~
Family Myriopathidae	*Plumapathes pennacea*			○	●
	Tanacetipathes hirta				●
Family Schizopathidae	*Bathypathes alternata*		●	○	~
	Parantipathes tetrasticha				●
Subclass Octocorallia					
Order Gorgonacea					
Family Acanthogorgiidae	*Acanthogorgia armata*	●			~

Higher Taxon	Species	Northeast	Southeast	Gulf of Mexico	Caribean
Family Anthothelidae	*Diodogorgia nodulifera*			○	●
Family Ellisellidae	*Ellisella barbadensis*			○	●
	Ellisella elongata			○	●
	Nicella deichmannae				●
	Nicella guadelupensis			○	●
	Nicella obesa				●
	Riisea paniculata			○	●
Family Isididae	*Acanella arbuscula*	○		●	
	Keratoisis flexibilis		○	●	~
	Keratoisis spp.	○	●		
Family Paragorgiidae	*Paragorgia arborea*	●			
Family Plexauridae	*Paramuricea grandis*	●			~
	Swiftia exserta				●
Family Primnoidae	*Acanthoprimnoa goesi*				●
	Callogorgia americana americana		○	○	●
	Callogorgia americana delta			●	
	Narella bellissima		○		●
	Narella pauciflora		○		●
	Primnoa resedaeformis	●			

STATE OF DEEP CORAL ECOSYSTEMS IN THE ALASKA REGION:

GULF OF ALASKA, BERING SEA AND THE ALEUTIAN ISLANDS

Robert P. Stone and S. Kalei Shotwell

I. INTRODUCTION

Alaska is the largest state in the U. S. and contains more than 70% of the nation's continental shelf habitat. The state has 55,000 km of tidal shoreline and the surface area of marine waters in the U.S. Exclusive Economic Zone (EEZ) measures approximately 3.3 million km^2. The region has a highly varied submarine bathymetry owing to the numerous geological and physical processes at work in the three main physiographic provinces – continental shelf, continental slope, and abyssal plain. The marine environment of the Alaska Region can be divided into three major geographical subregions – the Gulf of Alaska, the Bering Sea including the Aleutian Island Archipelago, and the Chukchi and Beaufort Seas in the Arctic.

Deep corals are widespread throughout Alaska, including the continental shelf and upper slope of the Gulf of Alaska, the Aleutian Islands, the eastern Bering Sea, and extending as far north as the Beaufort Sea. Coral distribution, abundance and species assemblages differ among geographic regions. Gorgonians and black corals are most common in the Gulf of Alaska while gorgonians and stylasterids are the most common corals in the Aleutian Islands. True soft corals are common on Bering Sea shelf habitats. Overall, the Aleutian Islands have the highest diversity of deep corals in Alaska, and possibly in the North Pacific Ocean, including representatives of six major taxonomic groups and at least 50 species or subspecies of deep corals that may be endemic to that region. In the Aleutian Islands, corals form high density "coral gardens" that are similar in structural complexity to shallow tropical reefs and are characterized by a rigid framework, high topographic relief and high taxonomic diversity (Stone 2006).

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A few coral species were described from Alaskan waters as early as the late1800's (Verrill 1865; Dall 1884), but the true magnitude of Alaska's coral resources was not realized until the U.S. Fisheries Steamship *Albatross* brought back evidence of rich beds of corals in 1888. The *Albatross* Expedition continued through 1906 in Alaskan waters and collections made during that period initiated the first detailed taxonomic work on Alaskan octocorals (Nutting 1912) and hydrocorals (Fisher 1938). With specific regard to hydrocorals Fisher (1938) noted that "the North Pacific is far richer in indigenous species than the North Atlantic." Collections made since that time, mostly opportunistic rather than from directed expeditions, have resulted in subsequent taxonomic work on octocorals (Bayer 1952; Bayer 1982; Bayer 1996), antipatharians (Opresko 2005), and a synthesis on scleractinian corals (Cairns 1994).

Most information on coral distribution in Alaska is based on fisheries by-catch and stock assessment survey data. Consequently, our knowledge of coral distribution is largely limited, and somewhat biased, to those geographic areas and depth zones where fisheries and stock assessment surveys have occurred. Nonetheless, given the widespread nature of existing fisheries and surveys in the state, the distribution of coral from these sources provides a fairly accurate depiction of the true distribution of corals. Few directed studies have been undertaken until recently to examine the ecology and distribution of deep corals. Cimberg et al. (1981) compiled a synthesis of coral records from Alaskan waters specifically to address concerns about oil and gas exploration and development on the outer continental shelf. Some information on coral distribution has been opportunistically collected during nearshore scuba and submersible surveys focused on fish stock assessments, fish habitat

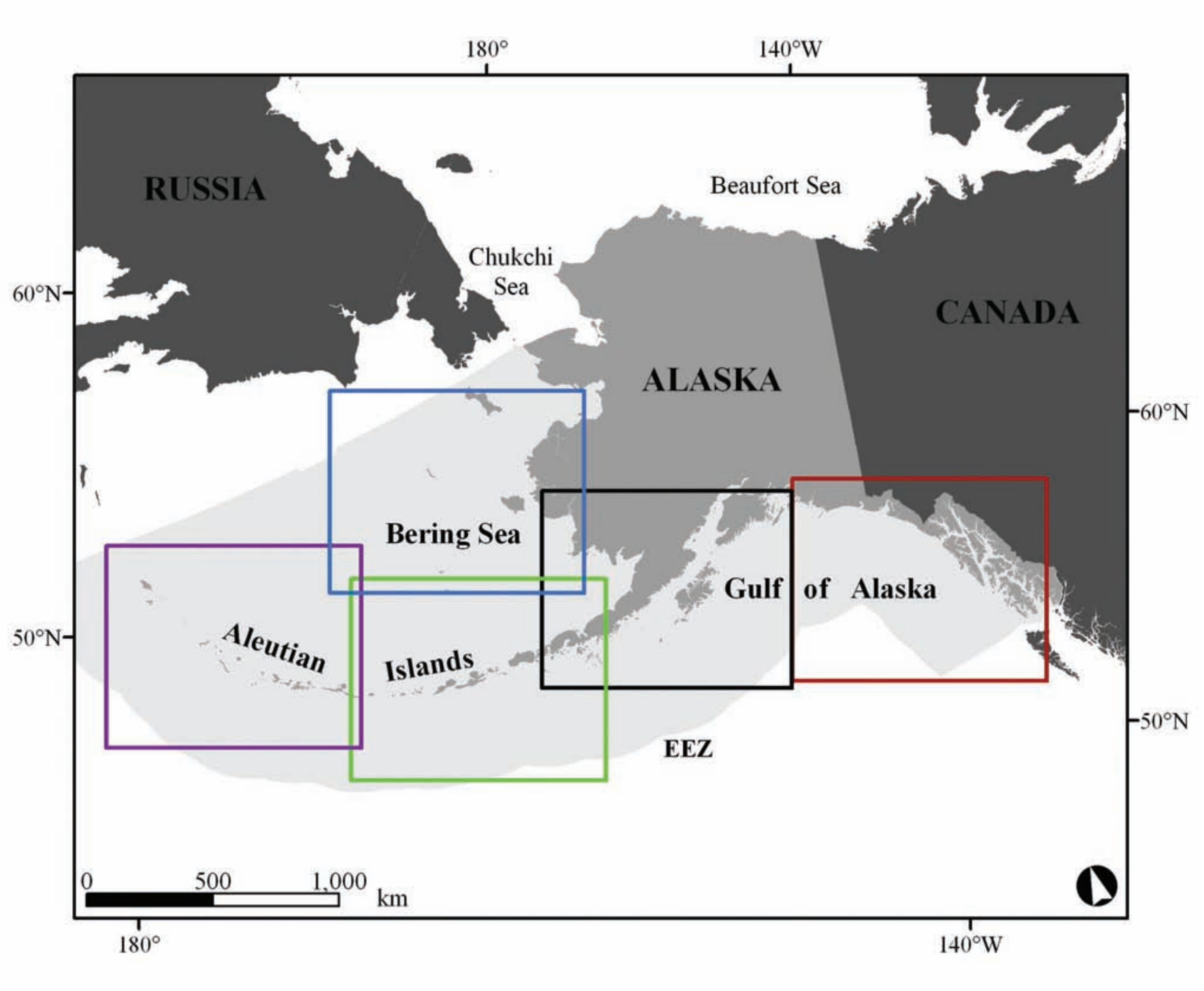

Figure 2.1. Map of Alaska showing the 5 broad geographical areas that were delineated for this report. From east to west – eastern Gulf of Alaska (red box), western Gulf of Alaska (black box), eastern Aleutian Islands (green box), western Aleutian Islands (purple box), and Bering Sea (blue box).

assessments, and studies on the effects of fishing gear on fish habitat.

Two major research programs were recently initiated in largely unexplored areas of Alaska and findings from those studies, although preliminary, have greatly increased our knowledge on the distribution of deep corals. Following an exploratory cruise in 2002, a multi-year study was initiated to investigate coral habitat in the central Aleutian Islands using the manned submersible *Delta* and the remotely operated vehicle (ROV) *Jason II*. The National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA/NMFS), the North Pacific Research Board (NPRB), and NOAA's Undersea Research Program (NURP) sponsored this research. In 2002 and 2004, a multi-discipline study using the manned submersible *Alvin* was launched to investigate seafloor habitat on North Pacific Ocean seamounts. A total of seven seamounts within the U. S. EEZ were explored during the two-year study. An additional seamount located south of the Alaska Peninsula was explored with the ROV *Jason II* in 2004. NOAA's Office of Ocean Exploration (OE) and NURP sponsored the seamount studies

In this chapter, detailed descriptions of deep coral habitat found in Alaskan waters are provided along with a discussion of their distribution, threats to deep coral habitat, and current management and conservation measures. Five broad geographical areas of Alaska (Figure 2.1) were delineated as follows: 1) the eastern Gulf of Alaska (GOA) including the inside waters of the

Alexander Archipelago, Southeast Alaska, 2) the western GOA including the Alaska Peninsula, 3) the eastern Aleutian Islands (Shumagin Islands to Seguam Pass), 4) the western Aleutian Islands (Seguam Pass to Stalemate Bank), and 5) the Bering Sea.

Coral records from these areas were categorized into the six major taxonomic groups. Three ecologically important groups of gorgonians, *Primnoa* spp., *Paragorgia* spp., and bamboo corals (Family Isididae) are categorized separately because their large size and conspicuous morphology greatly reduce the probability of inaccurate field identification.

The principal source of information on coral distribution is by-catch data collected during NMFS research trawl surveys (Resource Assessment and Conservation Engineering Database (RACEBASE)), Alaska Fisheries Science Center (AFSC), Resource Assessment and Conservation Engineering Division's Groundfish Assessment Program). Although RACEBASE includes records of research cruises since 1954, data collected prior to 1975 are not included in this report because the catch of corals was not always recorded and the accuracy of onboard coral identifications made before that time is questionable. By-catch data collected during the AFSC sablefish longline survey in 2004, published records, and unpublished *in situ* observations were also used to map coral distributions. There is very limited survey and fishery information from the Alaskan Arctic (Chukchi and Beaufort Seas).

II. GEOLOGICAL SETTING

The Gulf of Alaska

The Gulf of Alaska has a broad continental shelf extending seaward up to 200 km in some areas and contains several deep troughs (National Academy of Sciences 1990). In the eastern Gulf of Alaska, the Pacific Plate moves roughly parallel to the North American Plate, along the Fairweather-Queen Charlotte fault, and forms an abrupt continental slope with an abbreviated shelf (NURP 1996). In the northern and western parts of the Gulf of Alaska, the two plates slide, rather than slip past each other, and form a convergent margin and subduction zone (NURP 1996). Gulf of Alaska continental shelf habitats include steep rock outcrops, smooth turbidite sediment scapes, and methane seeps (NURP 2001). The nature of the seabed on the Gulf of Alaska shelf has been strongly influenced by glaciation and high rates of sediment deposition. The Gulf of Alaska also contains approximately 24 major seamounts arranged in three chains extending north from the Juan de Fuca Ridge. The seamounts are volcanoes rising from the abyssal plain that were likely formed as the Pacific Plate moved over mantle hotspots.

The Bering Sea

The Bering Sea is a shallow sea and has one of the largest continental shelves in the world – 1200 km long and 500 km wide (National Academy of Sciences 1990). The continental shelf breaks at approximately 170 m depth and seven major canyons, including the Zhemchug and Bering Canyons—the two largest submarine canyons in the world (Normark and Carlson 2003), indent the continental slope (Johnson 2003). The continental shelf is covered with sediment deposited by the region's major rivers (Johnson 2003) and therefore has limited hard substrate for coral attachment. The Aleutian Island Archipelago contains more than 300 islands and extends over 1900 km from the Alaska Peninsula to the Kamchatka Peninsula in Russia. The Archipelago is supported by the Aleutian Ridge and it forms a semi-porous boundary between the deep North Pacific Ocean to the south and the shallower Bering Sea to the north. The Aleutian Ridge is a volcanic arc with more than 20 active volcanoes and frequent earthquake activity that was formed along zones of convergence between the North American Plate and other oceanic plates (Vallier et al. 1994). The island arc shelf is very narrow in the Aleutian Islands and drops precipitously on the Pacific side, to depths greater than 6000 m in some areas, such as the Aleutian Trench.

The Alaskan Arctic

The Bering Strait separates the Bering Sea from the Chukchi Sea. The Chukchi Sea is a shallow shelf (only 20 to 60 m deep). The continental shelf in the Beaufort Sea is fairly broad (80-140 km wide) and is a submarine extension of the North Slope coastal plain (Horowitz 2002). Sediments on the continental shelf are predominantly soft and fine-grained and are redistributed by long-shore currents, wave action, entrainment in bottom-fast ice, ice gouging, ocean currents, and internal waves (Horowitz 2002).

III. OCEANOGRAPHIC SETTING

Major oceanic currents are found in all three subregions of Alaska and variations in their circulation control the climate and oceanic patterns in the North Pacific and Arctic Oceans. Currents likely influence larval dispersal and consequently the distribution of deep corals. Major oceanic currents influence the water temperature regimes in the subregions that may affect the growth rates for some species of deep corals.

The Gulf of Alaska

Two primary ocean currents exist in the Gulf of Alaska that flow around the Alaska Gyre. The Alaska Current is a wide (>100 km), slow moving (0.3 m s^{-1}) current that flows northward off the shelf of the eastern Gulf of Alaska. It becomes the Alaska Stream west of Kodiak Island where it narrows (<60 km), increases speed (1 m s^{-1}) and continues to flow westward south of the Alaska Peninsula and Aleutian Island Archipelago (Royer 1981). Continental shelf circulation is strongly influenced by freshwater input, and nearshore currents are additionally influenced by shelf bathymetry (Allen et al. 1983). Some areas of the Gulf of Alaska have among the largest tides in the world (Cook Inlet has the 2nd largest tidal amplitude in North America, after the Bay of Fundy in Atlantic Canada) and circulation is strongly tidally influenced in those areas. Several physical processes enhance regional nutrient supply and primary productivity and include costal upwelling, river discharge, tidal mixing, estuarine circulation, mesoscale eddy formation and transport, and recirculation around the Alaska Gyre (Whitney et al. 2005).

The Bering Sea

The Aleutian Archipelago forms the boundary between the deep North Pacific Ocean and the shallower Bering Sea. Deep water flowing northward in the Pacific Ocean encounters the Aleutian Trench where it is forced up onto the Aleutian Ridge and into the Bering Sea through the many island passes (Johnson 2003). Additionally, coastal water from the Alaska Stream enters through Unimak Pass in the eastern Aleutians and slowly (0.01 to 0.06 m s^{-1}) flows northeastward along the Alaska Peninsula. The Aleutian North Slope Current flows eastward on the north side of the Aleutian Islands towards the inner continental shelf of the Bering Sea. This is a swift current (0.5 m s^{-1}) and the steep continental slope forces much of the flow into the northwest flowing Bering Slope Current (Johnson 2003).

The Bering Slope Current flows northwestward off the shelf break and together with currents on the northern shelf flows northward through the Bering Strait and into the Chukchi Sea (Kinder and Schumacher 1981). Tidal currents dominate circulation in the southeastern shelf area of the Bering Sea (Kinder and Schumacher 1981). On the outer shelf currents flow along isobaths to the northwest at speeds up to 0.1 m s^{-1}.

The Alaskan Arctic

North Pacific waters flow from the Bering Sea, across the Bering Strait and into the Chukchi Sea in the Arctic. Consequently, the Chukchi Sea has more faunal affinities to the North Pacific than to the deeper Beaufort Sea. Different circulation regimes exist on the inner and outer continental shelves of the Beaufort Sea (Aagaard 1984). Circulation on the inner shelf is to the west and strongly wind-driven. Outside the 50-m isobath, the Beaufort Undercurrent slowly (0.1 m s^{-1}) flows eastward.

IV. STRUCTURE AND HABITAT-FORMING DEEP CORALS

Coral communities in Alaskan waters are highly diverse and include six major taxonomic groups (Appendix 2.1): true or stony corals (Order Scleractinia), black corals (Order Antipatharia), true soft corals (Order Alcyonacea) including the stoloniferans (Suborder Stolonifera), sea fans (Order Gorgonacea), sea pens (Order Pennatulacea), and stylasterids (Order Anthoathecatae). One hundred and forty one unique coral taxa have been documented from Alaskan waters and include 11 species of stony corals, 14 species of black corals, 15 species of true soft corals (including six species of stoloniferans), 63 species of gorgonians, 10 species of sea pens, and 28 species of stylasterids (Appendix 2.1). Note that all taxa listed in Appendix 2.1 are believed to be unique and include 52 taxa with incomplete taxonomy, including several that have only recently been collected and likely represent species new to science. All corals found in Alaska are azooxanthellate and satisfy all their nutritional requirements by the direct intake of food. They are ahermatypic or non-reef building corals but many are structure forming. The degree to which they provide structure depends on their maximum size, growth form, intraspecific fine-scale distribution, and interaction with other structure-forming invertebrates (Table 2.1).

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

At least 11 species of stony corals have been reported from Alaskan waters (Cairns 1994). All are solitary cups and the largest species measure less than 10 cm in total height. They require exposed, hard substratum for attachment. Unlike their tropical counterparts, they do not form significant structure used by larger fishes as refuge (Table 2.1). They are, however, contagiously distributed (i.e. aggregated or clumped) and dense patches may provide some structural habitat for some macro-invertebrates and juvenile fish (Figure 2.2).

b. *Black Corals* (Class Anthozoa, Order Antipatharia)

Black corals have some importance as structure-forming corals (Table 2.1) and at least 14 species are reported from Alaska (Appendix 2.1). They are locally abundant, contagiously distributed, and a few species such as *Dendrobathypathes boutillieri* (Opresko 2005) and *Parantipathes* sp. may grow over 1 m in height and/or width (Figure 2.3). Data from the NMFS sablefish longline survey indicate that several species

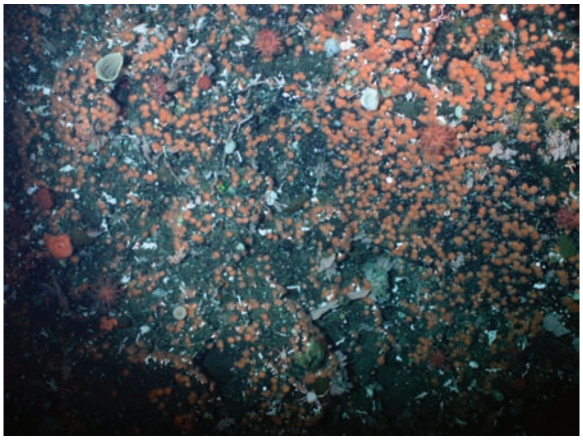

Figure 2.2. Scleractinians occasionally form dense patches, such as this one in Amchitka Pass (Aleutian Islands), that may provide refuge habitat for small fish and crustaceans. Photo by R. Stone, NOAA Fisheries.

Table 2.1. Structure-forming attributes of deep corals in Alaska.

Taxa	Reef-building	Abundance	Maximum colony size	Morphology	Associations with other structure forming invertebrates	Colony spatial dispersion	Overall rating of structural importance
Scleractinia	No	Low	Small	No-branch	Few	Clumped	Low
Antipatharia	No	Medium	Large	Branch	Few	Clumped	Medium
Alcyonacea	No	Medium	Small	No-branch	Few	Clumped	Medium
Stolonifera	No	Low	Small	No-branch	Few	Clumped	Low
Gorgonacea	No	High	Large	Branch	Many	Clumped	High
Primnoa spp.	No	High	Large	Branch	Many	Clumped	High
Paragorgia spp.	No	Medium	Large	Branch	Many	Clumped	High
Isididae	No	Medium	Large	Branch	Many	Clumped	High
Pennatulacea	No	High	Large	Branch	Few	Clumped	Medium
Anthoathecatae	No	High	Medium	Branch	Many	Clumped	High

Table Key

Attribute	Measure
Reef-Building	Yes/No
Relative Abundance	Low/ Medium/ High
Size (width or height)	Small (<30cm)/ Medium (30cm-1m)/ Large (>1m)
Morphology	Branching/ Non-branching
Associations	None/ Few (1-2)/ Many (>2)
Spatial Dispersion	Solitary/ Clumped
Overall Rating	Low/ Medium/ High

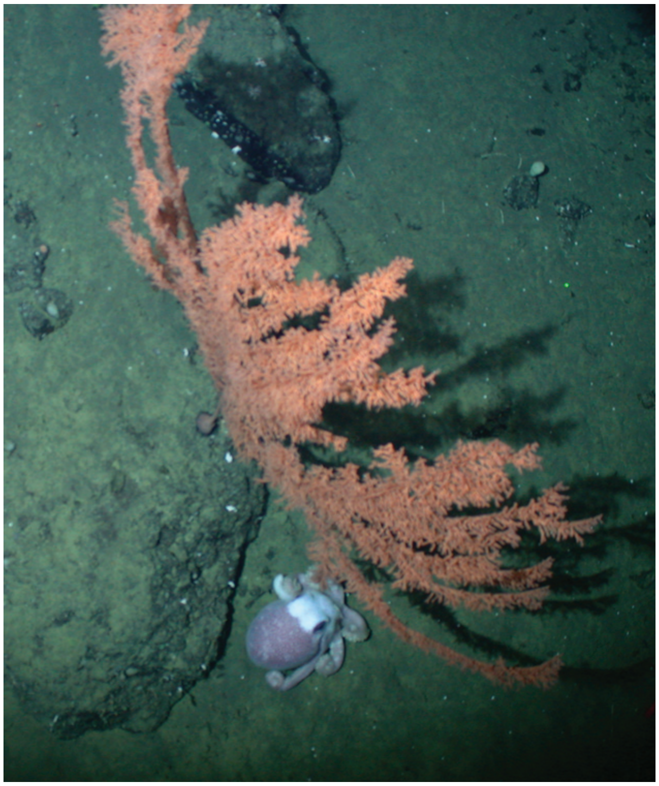

Figure 2.3. Some black corals such as this *Dendrobathypathes boutillieri* may reach heights over 1 m. An unknown species of octopus takes cover under the coral. Photo credit: R. Stone, NOAA Fisheries.

form dense patches in some areas of the Gulf of Alaska. Deep ROV observations in the central Aleutian Islands in 2004 confirmed that black corals are contagiously distributed with densities approaching 1 colony m^{-2} on some shelf habitats (R. Stone, unpublished data). They require hard substratum for attachment and by-catch specimens collected during NMFS groundfish surveys in the Gulf of Alaska were attached to small cobbles and mudstone.

c. *Gold Corals* (Class Anthozoa, Order Zoanthidae)

Gold corals or zoanthids are not known to occur in Alaskan waters but dense mats of zoanthid-like colonies similar to *Epizoanthus scotinus* known from British Columbia (Lamb and Hanby 2005) have been observed in eastern Gulf of Alaska habitats (R. Stone, personal observations).

d. Gorgonians (Class Anthozoa, Order Gorgonacea)

Gorgonians are the most diverse coral group in Alaskan waters – more than 60 species representing seven families have been reported (Appendix 2.1). Gorgonians are also the most important structure-forming corals in Alaskan waters (Table 2.1). They generally require exposed, hard substratum for attachment but recent observations in deep water (>450 m) indicate that the skeletons of hexactinellid sponges may be important attachment substrates in areas devoid of exposed rock (R. Stone, unpublished data). Gorgonians are locally abundant, contagiously distributed, and several species attain massive size. Gorgonians form both single- and multi-species assemblages. For example, *Primnoa pacifica* forms dense thickets in the Gulf of Alaska (Krieger and Wing 2002) while as many as 10 species are found in Aleutian Island coral gardens (Stone 2006). Some gorgonians are also extremely long lived. A medium-sized colony (197.5 cm length) identified as *Primnoa resedaeformis* (most likely *P. pacifica*) was aged at 112 years in the Gulf of Alaska (Andrews et al. 2002). *P. pacifica* attains a height of 7 m in the Gulf of Alaska (Krieger 2001) and *P. wingi* reaches a height of at least 1.5 m in the Aleutian Islands (R. Stone personal observations). The depth and geographical distribution of *Primnoa* spp. in Alaskan waters corresponds to the mean spring bottom temperature of 3.7°C (Cimberg et al. 1981) suggesting that this might be the low temperature of its tolerance range. *Paragorgia arborea* can measure 2 m high and wide, (Figure 2.5) and other gorgonians such as *Plumarella* sp., *Fanellia* sp., and bamboo corals (Family Isididae) grow to over 1 m high (R. Stone personal observations). The northern distribution of bamboo corals suggests

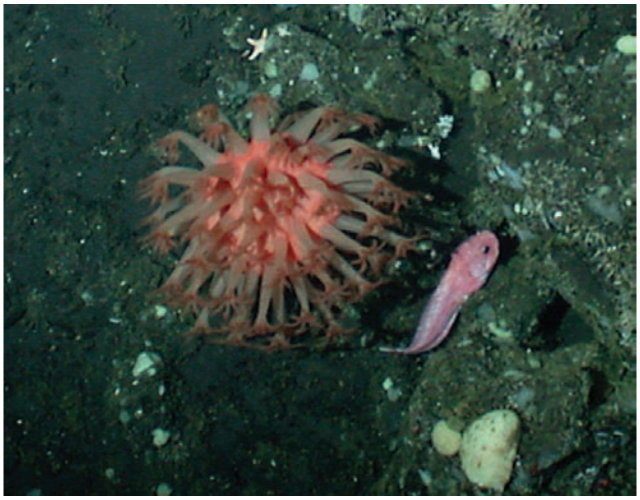

Figure 2.4. This true soft coral (*Anthomastus* sp.) measures 20 cm across and provides shelter for a snailfish (*Careproctus* sp.). Photo credit: R. Stone, NOAA Fisheries.

a temperature tolerance of less than 3.0°C and their distribution also suggests a low tolerance for high sedimentation (Cimberg et al. 1981).

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

True soft corals (Suborder Alcyoniina) are not a diverse group in Alaskan waters – only nine species are reported (Appendix 2.1). They have some importance as structure-formers (Table 2.1). Colonies are encrusting or erect and a few species (e.g., *Anthomastus ritterii*) may reach 20 cm in height (Figure 2.4) They require exposed, hard substratum for attachment, are locally abundant, and have a contagious distribution. *Eunephthea rubiformis* (formerly *Gersemia rubiformis*) are locally abundant on the unconsolidated sediments of the eastern Bering Sea shelf (Heifetz 2002) and although small, colonies may be abundant enough to provide important refuge habitat for juvenile fish and crustaceans. Additionally, six species of stoloniferans (Suborder Stolonifera) are reported from Alaska (Appendix 2.1) and they generally have little importance as structure-formers (Table 2.1). They can form extensive mats on hard surfaces such as rock, other corals, and sponges (Stone 2006). They are locally abundant – a single species of *Clavularia* was measured at a density of 1.7 colonies m^{-2} in one Aleutian Island coral garden (Stone 2006).

f. Pennatulaceans (Class Anthozoa, Order Pennatulacea)

Ten species of pennatulaceans (sea pens) are reported from Alaskan waters (Appendix 2.1) and several are important structure-forming corals (Table 2.1). Many species are elongate and whip-like and one species, *Halipteris willemoesi*, attains a height greater than 3 m (R. Stone personal observations). At least three species form extensive groves in soft-sediment areas. *Protoptilum* sp. and *H. willemoesi* form dense groves (16 m^{-2} and 6 m^{-2}, respectively) in the central Gulf of Alaska (Stone et al. 2005). Dense groves of *H. willemoesi* have also been reported on the Bering Sea shelf (Brodeur 2001). *Ptilosarcus gurneyi* also forms dense groves on shallow shelf habitats throughout the Gulf of Alaska and Aleutian Islands (Figure 2.6).

Figure 2.6. Dense groves of the sea pen *Ptilosarcus gurneyi* are found on soft-sediment shelf habitats in the Gulf of Alaska and Aleutian Islands. Photo credit: P. Malecha, NOAA Fisheries.

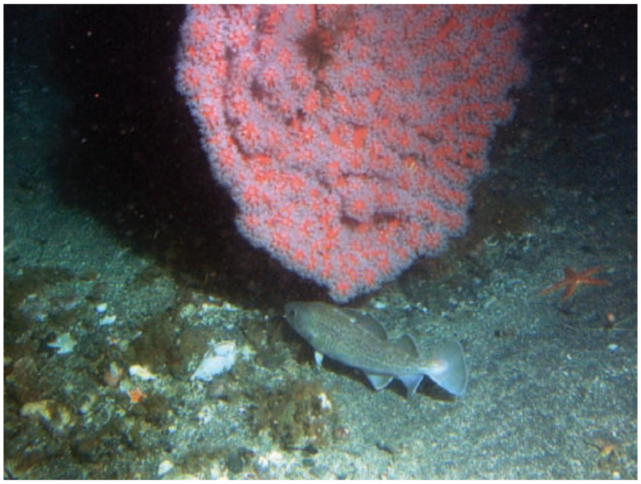

Figure 2.5. A large bubblegum coral (*Paragorgia arborea*) provides shelter for a Pacific cod (*Gadus macrocephalus)* in the central Aleutian Islands. Photo credit: R. Stone, NOAA Fisheries.

g. Stylasterids (Class Hydrozoa, Order Anthoathecatae)

More than 25 species or subspecies are reported from Alaskan waters (Wing and Barnard 2004; Appendix 2.1) and many are important structure-forming corals (Table 2.1). They form erect (e.g., *Stylaster* spp.) or encrusting calcareous colonies (e.g., *Stylantheca petrograpta*), and require exposed, hard substratum for attachment (Figure 2.7). Some erect species, most notably *Stylaster cancellatus*, may grow to almost one meter in height and often display contagious distributions. Stylasterids, particularly *Stylaster campylecus*, are a major structural component of Aleutian Island coral gardens and are often encrusted with the demosponge *Myxilla incrustans* – together they form a rigid platform that other sedentary and sessile invertebrates use as an elevated feeding platform (Stone 2006). Encrusting species, such as *S. petrograpta*, have low value as structure-forming invertebrates.

V. SPATIAL DISTRIBUTION OF CORAL SPECIES AND HABITAT

Deep corals are widespread in Alaska and have been reported as far north as the Beaufort Sea (Cimberg et al. 1981). Corals are found over a broad depth range and occur from the shallow subtidal zone to the deep ocean trenches (Table 2.2). For example, pennatulaceans have been found as shallow as 3 m depth and antipatharians and gorgonians have been found at a depth of 4784 m on Gulf of Alaska seamounts. They are found in all megahabitats and mesohabitats as described by Greene et al. (1999). In addition to general factors controlling coral distribution such as current regimes and the presence of hard substrates, temperature tolerance appears to play a role in the geographic and depth distribution of some deep corals.

Eastern Gulf of Alaska

Deep corals have a widespread but patchy distribution on the continental shelf and slope in the eastern Gulf of Alaska (Figure 2.8). Approximately 46 species are reported from the area (Appendix 2.1). Only the Aleutian Islands support a higher diversity of corals. Corals include four species of stony corals, nine species of black corals, four species of true soft corals (including two stoloniferan species), thirteen species or subspecies of gorgonians, seven species of pennatulaceans, and nine species or subspecies of stylasterids (Appendix 2.1).

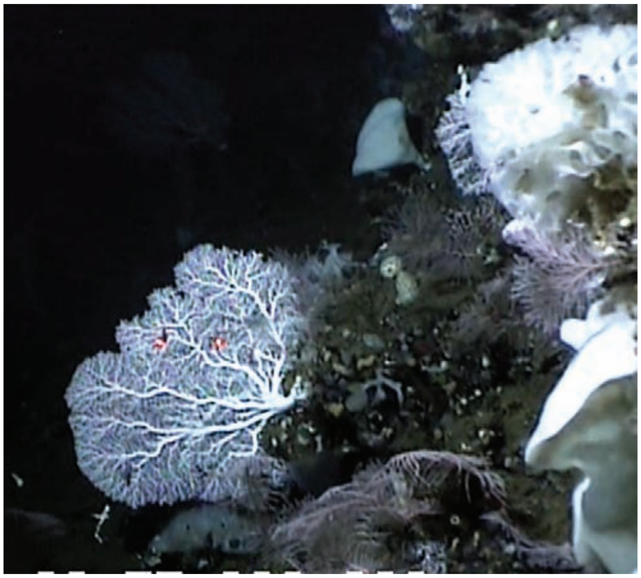

Figure 2.7. Large, erect stylasterids (*Stylaster* sp). grow on exposed bedrock with their central axis perpendicular to the current in the Aleutian Islands. Red laser marks are separated by 10 cm. Photo credit: R. Stone, NOAA Fisheries.

Corals range in depth from 6 m for *Primnoa pacifica* in the glacial fiords of Glacier and Holkham Bays (Stone et al. in preparation) to over 400 m on the continental slope. *P. pacifica* is found throughout the subregion and forms dense thickets in some areas, especially in the inside waters of Southeast Alaska and on high-relief rocky areas of the continental shelf (Figure 2.8A). It grows on bedrock and boulders and has been observed *in situ* at a depth of 365 m (Krieger 2001). Anecdotal information exists that it may grow as deep as 772 m in some areas of Southeast Alaska (Cimberg et al. 1981). Stylasterids are fairly common on the continental shelf and in some shallow areas of Southeast Alaska (Figure 2.8B). Black corals grow on the continental shelf at depths between 401 and 846 m (Figure 2.8C). Stony corals and soft corals are known from only a few locations (Figure 2.8D and 2.8E).

Calcigorgia spiculifera is another important gorgonian in Southeast Alaska that forms small groves on bedrock in shallow water areas (Stone and Wing 2001). The pennatulaceans, *Halipteris willemoesi* and *Ptilosarcus gurneyi* also form dense groves in some areas (Figure 2.8F) at depths between 20 and 200 m (Malecha et al. 2005). The most ecologically important coral feature in this subregion of Alaska is the *Primnoa* thickets on the continental shelf of the eastern Gulf of Alaska (Figure 2.8A). In July 2006, NMFS closed five small areas where *Primnoa* thickets have been documented via submersible observations to all fishing activities using bottom-contact gear.

Western Gulf of Alaska

Deep corals have a widespread but patchy distribution in the western Gulf of Alaska (Figure 2.9). Gorgonians are widely distributed on the continental shelf and slope (Figure 2.9A) and are represented by 13 species (Appendix 2.1). *Primnoa* sp. is the most common gorgonian with unconfirmed reports of dense thickets in the area of Chirikof Island (Cimberg et al. 1981). Bamboo corals are patchily distributed on the continental slope and records of *Paragorgia* spp. are rare (Figure 2.9A). Stylasterids are widely distributed (Figure 2.9B) but are not abundant or diverse. Only two species have been reported from this subregion (Appendix 2.1). Black corals, stony corals, and soft corals have only

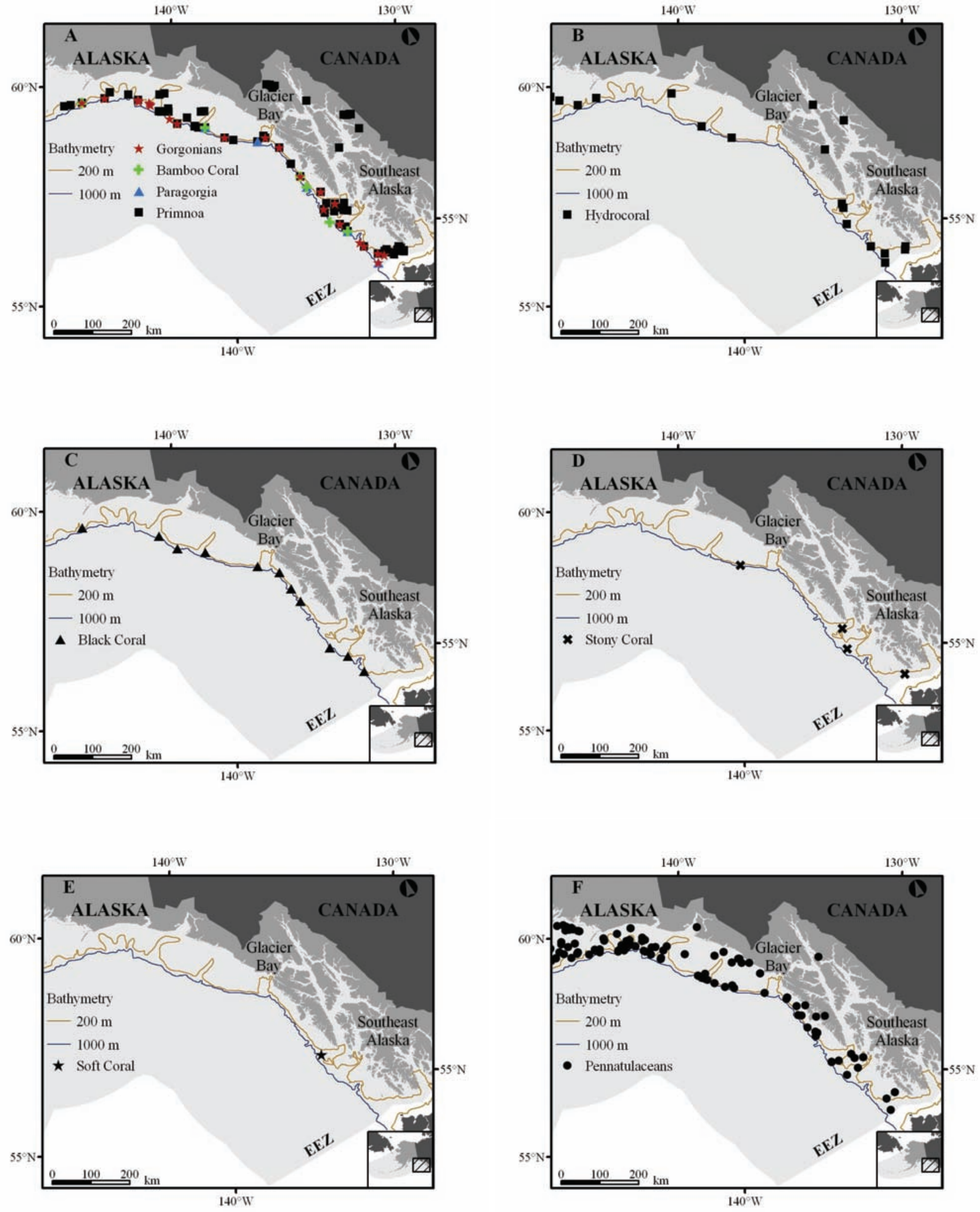

Figure 2.8. Distribution of corals in the eastern Gulf of Alaska A) gorgonians (bamboo corals – Family Isididae, *Paragorgia* spp., *Primnoa* spp. are plotted separately), B) stylasterids, C) black corals, D) stony corals, E) soft corals, and F) pennatulaceans.

Table 2.2. Summary of species richness and depth range for seven major groups of corals found in Alaskan waters. Data sources for depth distribution: 1. A. Baco-Taylor, unpublished data; 2. Hoff and Stevens 2005; 3. Keller 1976; 4. R. Stone, unpublished data; 5. Stone et al. in preparation; 6. Stone 2006.

Taxa	Number of Species	Depth range (m)	Data source shallow - deep
Scleractinia	11	24 - 4620	4 - 3
Antipatharia	14	401 - 4784	4 - 1
Alcyonacea	9	10 - 3209	4 - 2
Stolonifera	6	11 - 591	6 - 4
Gorgonacea	63	6 - 4784	5 - 1
Pennatulacea	10	3 - 2947	4 - 4
Anthoathecatae	28	11 - 2130	6 - 4
Total	141	3 - 4784	

been reported from a few areas (Figures 2.9C, 2.9D, 2.9E). The most ecologically important coral feature in this subregion of Alaska is the extensive pennatulacean groves (Figure 2.9F) in the submarine gullies south and east of Kodiak Island (Stone et al. 2005) and in isolated locations in Prince William Sound (Malecha et al. 2005).

Gulf of Alaska Seamounts

Submersible observations in 2002 and 2004 confirmed by-catch records that seamounts in the Gulf of Alaska are rich in coral habitat and that all major taxonomic groups except stylasterids were present (Appendix 2.1) (A. Baco-Taylor, WHOI, pers. comm.). The absence of stylasterids from the Gulf of Alaska seamounts is notable since they are common on the seamounts near New Zealand (Cairns 1991; Cairns 1992). Pennatulaceans are also noticeably uncommon from the seamounts and are represented by a single unidentified species (Appendix 2.1). The submersible *Alvin* was used during a 2004 research cruise to five seamounts in the northern Gulf of Alaska (Dickens, Denson, Welker, Giacomini, and Pratt) to collect video footage and specimens on transects along three depth strata: 700 m, 1700 m, and 2700 m. Corals were most abundant near the seamount summits (700 m) where *Paragorgia* spp. and bamboo corals were the dominant coral fauna. Gorgonians (Primnoidae) were the most abundant corals at the 2700 m depth stratum. Corals were least abundant and diverse in the 1700 m depth zone where black corals and Primnoidae were dominant. Precious red coral (*Corallium* sp.) was collected from Patton Seamount and represented a northern range extension for the family Corallidae. Bamboo corals were a particularly diverse group with at least four genera collected on the seamounts (P. Etnoyer, Texas A&M University - Corpus Christi, pers. comm.).

Coral habitat on Derickson Seamount which crests at 2766 m south of the Alaska Peninsula was explored with the ROV *Jason II* in 2004. Black corals, bamboo corals, and other gorgonians (Primnoidae and Chrysogorgiidae) were observed on hard substrates at depths between 2766 and 4784 m (A. Baco-Taylor, WHOI, pers. comm.). Several specimens collected on this deep seamount represent species new to science and significant depth-range extensions. A single species of stony coral (*Fungiacyathus* sp.) was observed in soft-sediment areas. Species distribution differed between the eastern and northern flanks of the seamount and highlights the importance of circumnavigating seamounts during surveys of coral distribution.

The Aleutian Islands

The Aleutian Islands support the most abundant and diverse coral assemblages in Alaska (Appendix 2.1). A total of 101 coral species or subspecies have been reported from the Aleutian Islands (Appendix 2.1). Previous reports indicated that 25 coral taxa were endemic to the region (Heifetz et al. 2005) – our updated records however, indicate that as many as 51 species may be endemic to the region! Deep-water collections made with the ROV *Jason II* in 2004 may add dozens of corals – novel species and range extensions – to this list. Gorgonians and stylasterids are the most diverse groups with 45 and 25 species or subspecies reported, respectively (Appendix 2.1). Twelve species of true soft corals including three species of stoloniferans, six species of pennatulaceans, and ten species of stony corals have also been reported from the subregion (Appendix 2.1). Additionally, three species of black corals were collected from the area in 2004 (R. Stone,

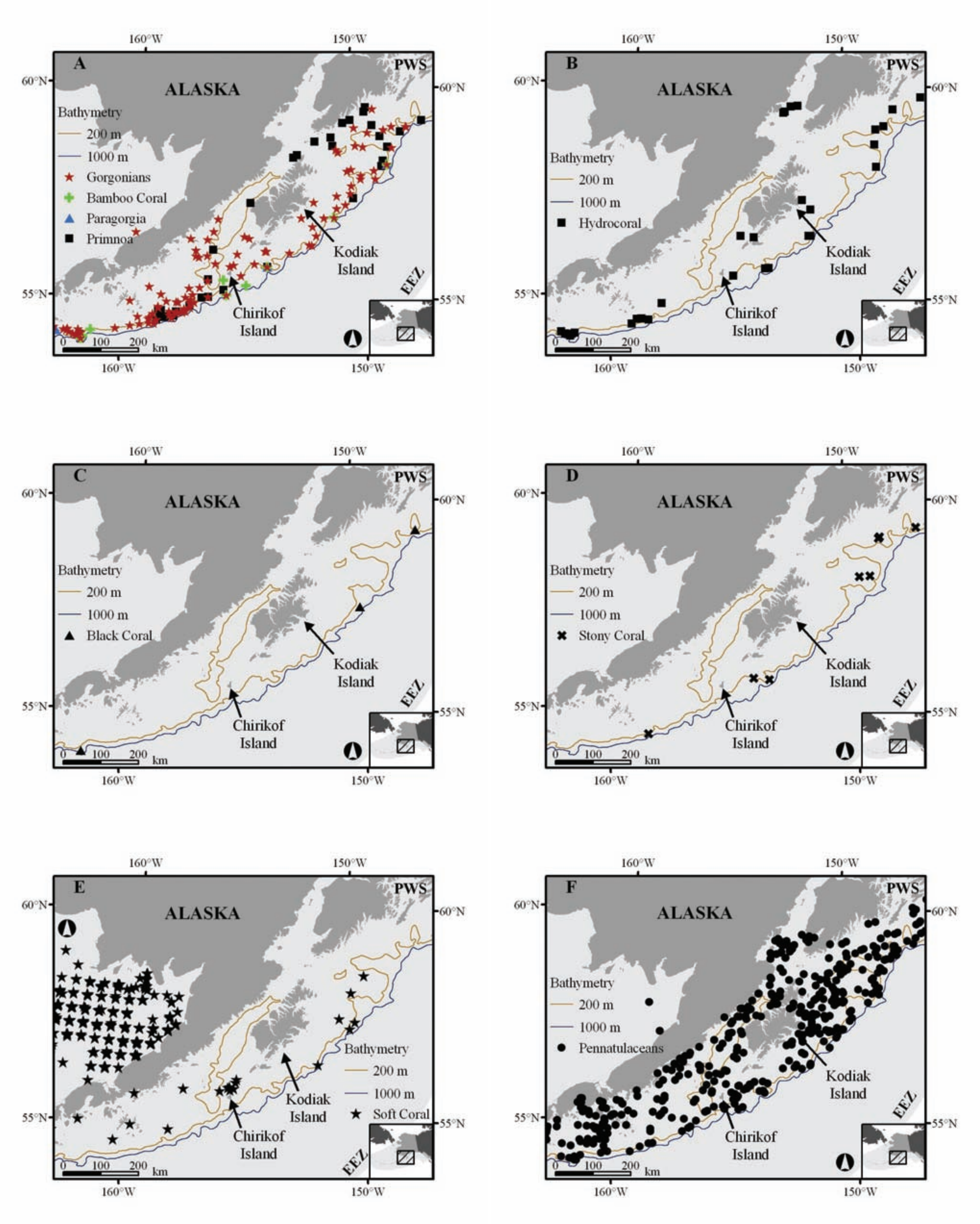

Figure 2.9. Distribution of corals in the western Gulf of Alaska A) gorgonians (bamboo corals – Family Isididae, *Paragorgia* spp., *Primnoa* spp. are plotted separately), B) stylasterids, C) black corals, D) stony corals, E) soft corals, and F) pennatulaceans.

unpublished data) including *Dendrobathypathes boutillieri*, a species new to science (Opresko 2005).

Eastern Aleutian Islands
Data from NMFS stock assessment surveys indicate that a major shift in coral diversity occurs in the eastern Aleutian Islands at about longitude 169° W near the west end of Umnak Island (Heifetz et al. 2005). Approximately twelve species of stylasterids, nine species of gorgonians, and three species of stony corals found further west in the Aleutian Islands are not found east of this area (Heifetz et al. 2005).

Gorgonians are widely distributed on the continental shelf and upper slope (Figure 2.10A). *Primnoa* spp. and *Paragorgia* spp. are widely distributed but few bamboo corals have been reported from the area (Figure 2.10A). Stylasterids are widely distributed especially along the south side of the archipelago (Figure 2.10B). Few black corals have been reported (Figure 2.10C) but stony corals and soft corals are widespread and abundant in some areas (Figures 2.10D, 2.10E). Pennatulaceans are widely distributed and likely form dense groves in some areas (Figure 2.10F).

Western Aleutian Islands
Corals are abundant and widespread in the western Aleutian Islands (Figure 2.11). Coral gardens, a previously undocumented habitat feature in the North Pacific Ocean, were observed with the submersible *Delta* at six locations in the central Aleutian Islands during 2002 (Stone 2006). Gardens are typically located in small, discrete patches at depths between 117 and 338 m and are distinguishable from other habitats by extremely high coral abundance (3.85 corals m^{-2}), especially gorgonians (1.78 colonies m^{-2}), and stylasterids (1.46 colonies m^{-2}).

In general, corals appear to have a much broader depth distribution in the western Aleutian Islands than elsewhere in Alaska. The depth distribution of *Primnoa* spp. (304–1436 m) is substantially deeper than elsewhere in Alaska (Stone 2006; R. Stone, unpublished data). Bamboo corals and *Paragorgia* spp. also have a very broad geographical distribution (Figure 2.11A). Bamboo corals have been observed at depths between approximately 400 and 2827 m (R. Stone, unpublished data) and have been collected with a beam trawl at a depth of 3532 m (Cimberg et al. 1981). *Paragorgia* spp. has been observed *in situ* at depths between 27 m (Stone 2006) and 1464 m (R. Stone, unpublished data). Stylasterids are widespread (Figure 2.11B) and have been observed at depths between 11 m (Stone 2006) and 2130 m (R. Stone, unpublished data). Black corals appear to have a limited distribution (Figure 2.11C) and have been observed on bedrock, boulders, and cobbles at depths between 449 and 2827 m (R. Stone, unpublished data).

Stony corals have a fairly broad distribution in this region of Alaska (Figure 2.11D) and have been collected at depths between 24 m (R. Stone, unpublished data) and 4620 m in the Aleutian Trench (Keller 1976). True soft corals are also fairly common in this region of Alaska (Figure 2.11E) and have been observed at depths between 10 m and 2040 m (R. Stone, unpublished data). Pennatulaceans have been observed as deep as 2947 m and form extensive groves in some soft-sediment areas on both shelf and slope habitats (Figure 2.11F).

The Bering Sea
Deep corals have a patchy distribution in this region of Alaska and are largely limited to the broad, shallow continental shelf and along the narrow continental slope (Figure 2.12). The entire north side of the Aleutian Archipelago is technically within the Bering Sea but for the purposes of this report we have defined the Bering Sea as those areas of the shelf and slope not immediately adjacent to the Aleutian Islands (as illustrated in Figure 2.12 and including the inner shelf illustrated in Figure 2.9). This definition applies both to the discussions in the text and to the species list provided in Appendix 2.1.

The coral fauna of this region of Alaska has been poorly documented but does not appear to be particularly diverse. Sixteen species or subspecies of coral are known from the region and include three species of true soft corals (including one species of stoloniferan), six species of gorgonians, four species of pennatulaceans, and three species of stylasterids (Appendix 2.1). Additionally, at least one species of black coral, one species of stony coral, and one species of bamboo coral have been collected from the region but proper identifications were never made. These records effectively increase

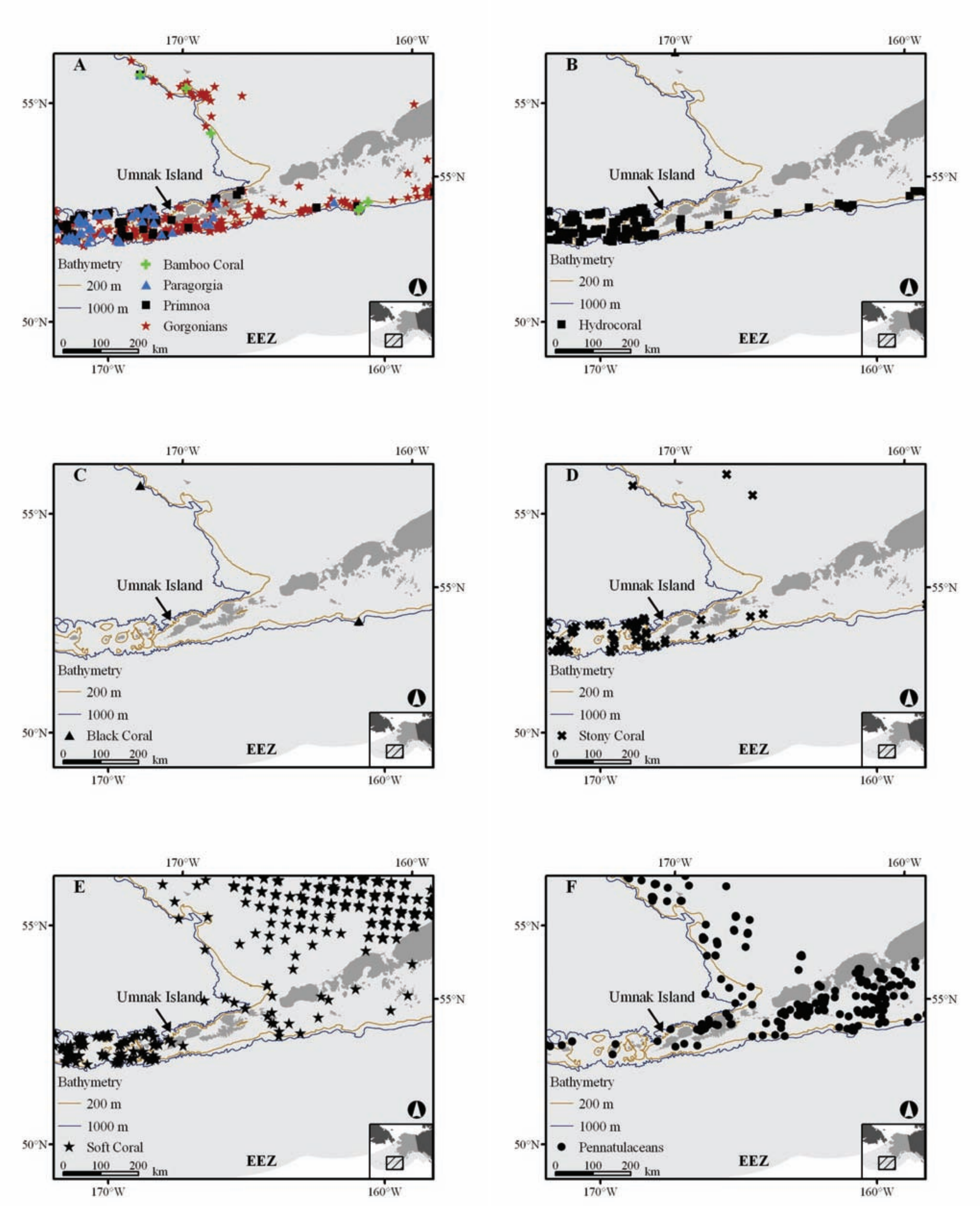

Figure 2.10. Distribution of corals in the eastern Aleutian Islands A) gorgonians (bamboo corals – Family Isididae, *Paragorgia* spp., *Primnoa* spp. are plotted separately), B) stylasterids, C) black corals, D) stony corals, E) soft corals, and F) pennatulaceans.

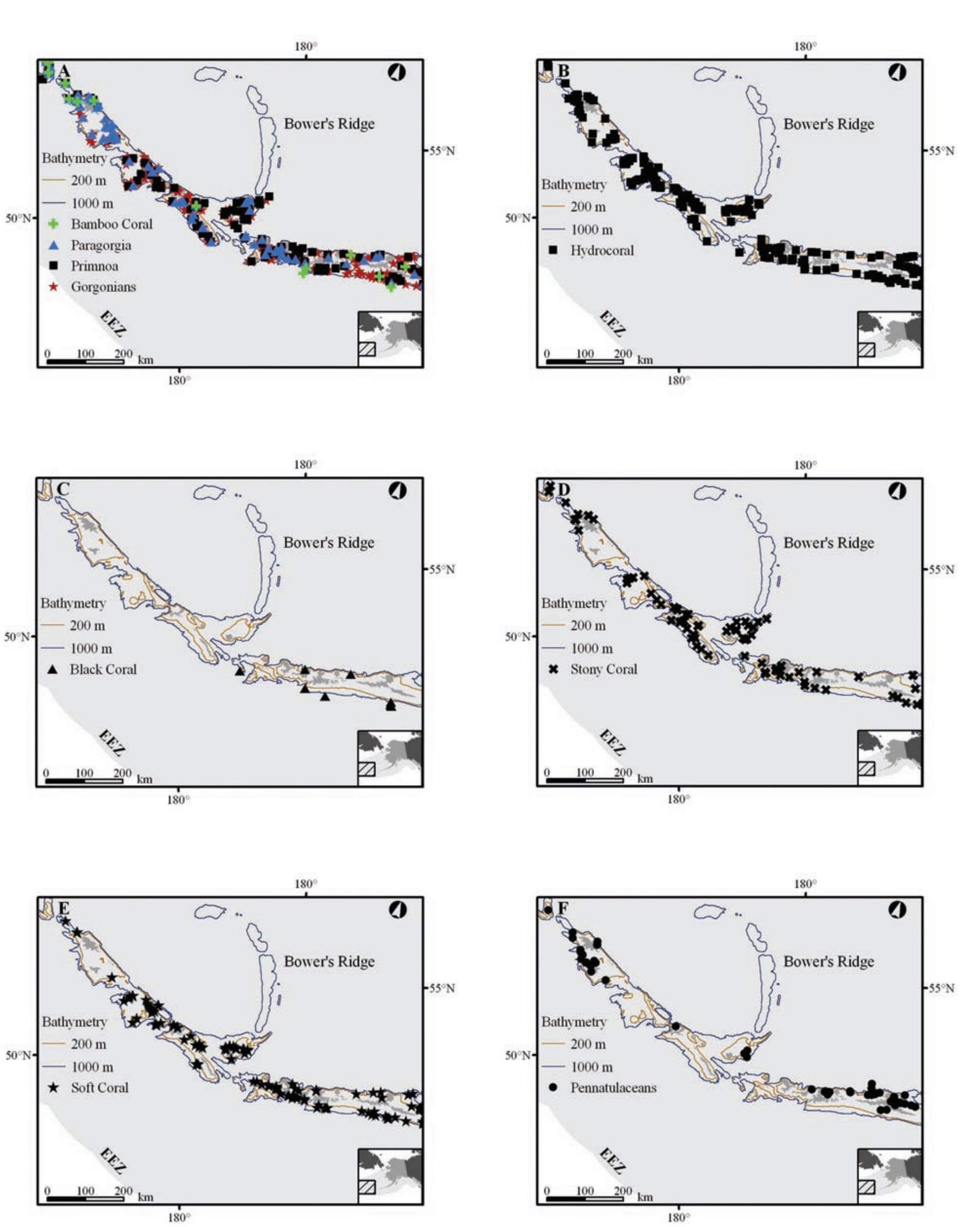

Figure 2.11. Distribution of corals in the western Aleutian Islands A) gorgonians (bamboo corals – Family Isididae, *Paragorgia* spp., *Primnoa* spp. are plotted separately), B) stylasterids, C) black corals, D) stony corals, E) soft corals, and F) pennatulaceans.

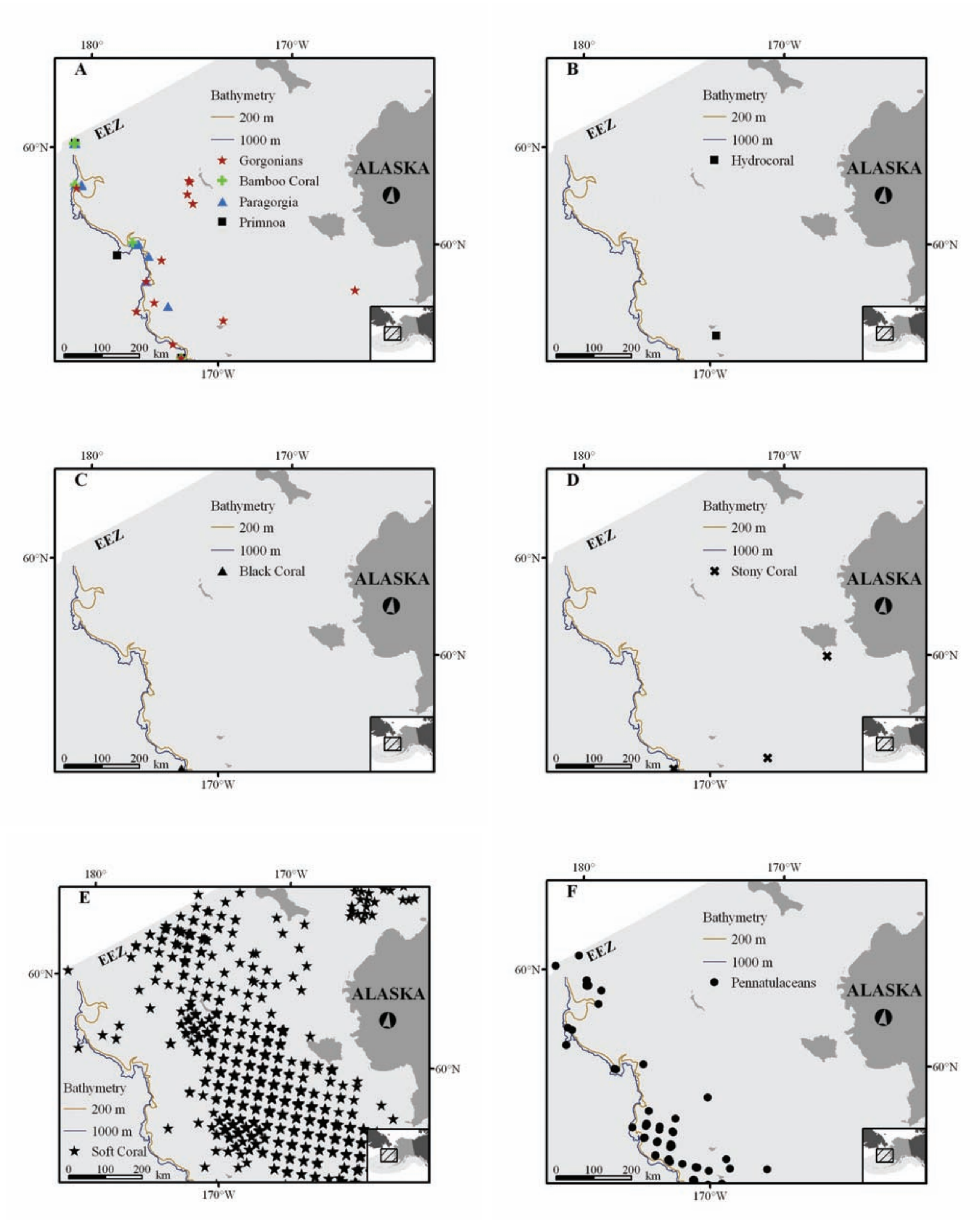

Figure 2.12. Distribution of corals in the Bering Sea A) gorgonians (bamboo corals – Family Isididae, *Paragorgia* spp., *Primnoa* spp. are plotted separately), B) stylasterids, C) black corals, D) stony corals, E) soft corals, and F) pennatulaceans.

the number of species in the region to at least nineteen. Gorgonians are distributed mostly on the continental slope and a few isolated shelf locations (Figure 2.12A). *Primnoa pacifica*, bamboo corals, and *Paragorgia* sp. have been collected from a few locations on the continental slope (Figure 2.12A). The bamboo coral specimens were collected during NMFS surveys and because definitive species identifications were not made they are not included in the species list (Appendix 2.1). Stylasterids have been reported from only a single location in the Pribilof Islands area (Figure 2.12B). Black corals have been reported from only a single location on the outer continental slope (Figure 2.12C) and stony corals are known from a few locations on shelf and slope locations (Figure 2.12D). The pennatulacean *H. willemoesi* forms dense groves on the outer continental shelf of the Bering Sea (Figure 2.12F) at depths between 185 and 240 m (Brodeur 2001; Malecha et al. 2005). The most important coral feature of the Bering Sea however, is likely the dense aggregations of soft corals (mostly *Eunephthea rubiformis*) on the unconsolidated sediments of the continental shelf (Figure 2.12E).

Alaskan Arctic

Only the soft coral *Eunephthea* sp. has been reported north of the Bering Sea (Cimberg et al. 1981). *Eunephthea* sp. is patchily distributed on the shallow shelves of the Chukchi and Beaufort Seas and has been reported as far north as 71º 24' N.

VI. SPECIES ASSOCIATIONS WITH DEEP CORAL COMMUNITIES

In Alaska, many commercial fisheries species and other species are associated with deep corals. Most associations are believed to be facultative rather than obligatory. Fish and crabs, particularly juveniles, use coral habitat as refuge and as focal sites of high prey abundance. Some shelter-seeking fishes such as rockfish may use coral habitat as spawning and breeding sites.

Commercial Fisheries Species Associations

In Alaska, commercial species are managed with five Fishery Management Plans (FMPs)—Bering Sea and Aleutian Island (BSAI) Groundfish, Gulf of Alaska Groundfish, BSAI King and Tanner Crabs, Salmon, and Scallops. The commercial harvest of approximately 35 species (or species groups) is specifically managed with the FMPs. Most of these species (approximately 85%) are found during some phase of their life cycle in deep-water habitats including those inhabited by deep corals so the potential for associations between commercial fish species and corals is high (Figures 2.14 and 2.15).

Figure 2.13. A shortspine thornyhead (*Sebastolobus alascanus*) rests in a field of primnoid gorgonians. Photo credit: R. Stone, NOAA Fisheries.

Heifetz (2002) analyzed data from RACE survey hauls to determine large-scale (i.e., kilometers to tens of kilometers) associations of commercially targeted fish species with corals. Rockfish (*Sebastes* spp.), shortspine thornyhead (*Sebastolobus alascanus*), and Atka mackerel (*Pleurogrammus monopterygius*) were the most common fish captured with gorgonians, scleractinians, and stylasterids. Flatfish (Pleuronectidae and Bothidae) and gadids were the most common fish captured with soft corals.

Stone (2006) examined fine-scale (<1 m) associations of FMP species with corals and other structure-forming invertebrates from video footage of the seafloor collected in the central Aleutian Islands. At the sites surveyed, 84.7% of the commercially important fish and crabs were associated with corals and other sedentary structure-providing invertebrates. All seven species of rockfish (*Sebastes*) observed were highly associated with corals. Associations ranged from 83.7% for "other" rockfish to 98.5% for sharpchin rockfish (*S. zacentrus*). Ninety seven percent of juvenile rockfish were associated with corals. Over 20% of the FMP species were in physical contact with corals and other structure-forming invertebrates.

Observations from the manned submersible *Delta* in the eastern Gulf of Alaska have documented fine-scale associations (<1 m) of adult shortraker (*S. borealis*), rougheye (*S. aleutianus*), redbanded (*S. babcocki*), sharpchin, dusky (*S. ciliatus*), and yelloweye rockfish (*S. ruberrimus*), and golden king crabs (*Lithodes aequispina*) with red tree coral *P. pacifica* (Krieger and Wing 2002). Large schools of Pacific ocean perch (*Sebastes alutus*) have been observed in dense groves of the pennatulacean *H. willemoesi* on the Bering Sea shelf presumably feeding on dense aggregations of euphausiids or krill (Brodeur 2001).

Only 16 of the 24 named seamounts in Alaskan waters summit within the maximum depth range of FMP species (approximately 3000 m). Several FMP species have been documented on the seamounts but studies have not been undertaken to examine associations of commercial species and coral habitat. FMP species documented on Alaskan seamounts include sablefish, longspine thornyhead (*Sebastolobus altivelis*), shortspine thornyhead, rougheye rockfish, shortraker rockfish, aurora rockfish (*Sebastes aurora*), and golden king crabs (Alton 1986; Hughes 1981; Maloney 2004). Other species of potential commercial importance found on the seamounts include the deep-sea sole (*Embassichthys bathybius*), spiny dogfish (*Squalus acanthias*), and several species of grenadiers (Family Macrouridae).

Figure 2.15. An unidentified eelpout (probably *Puzanovia rubra*) displays cryptic coloration in a *Paragorgia* colony at 746 m depth in the Aleutian Islands. Photo credit: R. Stone, NOAA Fisheries.

Other Species Associations

Many non-commercially important species are associated with deep corals in Alaska. Both facultative and obligatory associations are likely common. Few obligatory associations have been described to date but recent collections of micro- and macro-associates of corals should reveal new examples of unique adaptations and symbiosis. For example, three species of Aleutian eelpouts (*Nalbantichthys* sp., *Opaeophacus* sp., and *Puzanovia* sp.) have developed specializations such as cryptic coloration for life as adults in *Primnoa* (Anderson 1994) and *Paragorgia* colonies (Figure 2.15).

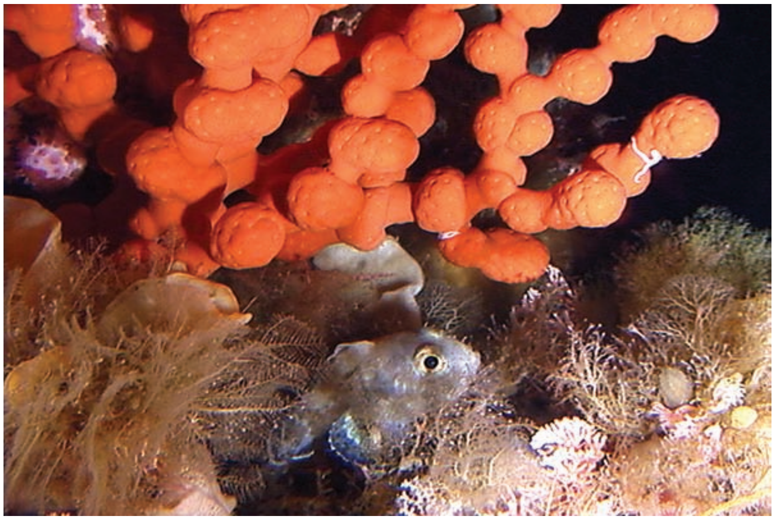

Figure 2.14. A darkfin sculpin *Malacocottus zonurus* rests under a bubblegum coral *Paragorgia arborea* in one of the seven coral gardens surveyed with the submersible *Delta*. Coral gardens are areas of extraordinary coral abundance and high species diversity. Photo credit: R. Stone, NOAA Fisheries.

Observations from the submersible *Delta* in the eastern Gulf of Alaska have documented fine-scale associations (<1 m) of sea anemones (*Cribrinopsis* sp., *Stomphia* sp., and *Urticina* sp.), the basket star (*Gorgonocephalus eucnemis*), the crinoid (*Florometra* sp.), and the nudibranch (*Tritonia exulsans*) with *P. pacifica* (Krieger and Wing 2002). All megafauna were in physical contact with the coral and were using it as an elevated feeding platform or as refuge. The spiny red sea star (*Hippasteria spinosa*) was documented preying on the coral. Macrofauna such as shrimp were also observed within the colonies but were not identified or enumerated.

Macrofaunal assemblages living on deep corals were studied during the Gulf of Alaska Seamount cruise in 2004. The chirostylid crab (*Gastroptychus iapsis*) and the basket star (*Asteronyx* sp.) were the most common macrofauna found on deep corals (T. C. Shirley, Texas A&M University, pers. comm.). Other macrofauna collected on corals included the hippolytid shrimp (*Heptacarpus* sp.), actiniarians, crinoids, ophiuroids, crustaceans, sea stars, pycnogonids, and nudibranchs. Taxonomic identifications are pending.

Macrofaunal assemblages living on deep corals collected during the Aleutian Island cruises in 2003 and 2004 were preserved and taxonomic identifications are underway. Crustaceans, ophiuroids, and polychaetes appear to be the most common macro-associates of octocorals (Les Watling, University of Hawaii, pers. comm.). The basket star *Asteronyx* sp. was highly associated with the deep-sea pennatulacean *Anthoptilum grandiflorum* and uses it as an elevated feeding platform (R. Stone, personal observations). Many sedentary and sessile taxa are found in close association with Aleutian Island corals and include sponges, hydroids, bryozoans, the crinoid *Florometra serratissima*, the sea cucumber *Psolus squamatus*, and the basket star *Gorgonocephalus eucnemis*. More than 100 different species of sponges, mostly demosponges, have been collected during the Aleutian Island studies and preliminary estimates indicate that more than 200 species of demosponges alone may occur in association with deep corals in the central Aleutian Islands (Stone 2006). Sea stars commonly found in Aleutian Island coral gardens include *Cheiraster dawsoni* and *Hippasteria spinosa* (R. Stone, unpublished data); the latter species is a documented predator of octocorals. Other predators of octocorals include snails of the genus *Otukaia* (family Calliostomatidae) that have recently been observed preying on bamboo corals in the Aleutian Islands (Figure 2.16).

Figure 2.16. Calliostomatid snails (genus *Otukaia*) prey on the soft flesh of an undescribed species of bamboo coral at a depth of 1227 m in the central Aleutian Islands. The snails were recently discovered and are currently being described by Dr. James McLean at the Natural History Museum of Los Angeles County. Photo credit: R. Stone, NOAA Fisheries.

There are no data regarding commercial fisheries or non-commercial species associations with coral habitat in the Arctic region of Alaska.

VII. STRESSORS ON DEEP CORAL COMMUNITIES

All known threats to deep coral communities in Alaska are directly or indirectly the result of human activities. While activities such as coastal development, point-source pollution, and mineral mining have the potential to affect nearshore habitats, the effects of these activities are geographically limited and occur or are likely to occur in areas with minimal coral habitat. Fishing activities, on the other hand, occur over vast areas of the seafloor and often in areas containing sensitive deep coral habitat. Human activities that may indirectly affect deep coral habitat include the introduction of invasive species and changes to the physical and chemical properties of the oceans due to global warming.

Effects of fishing

Diverse benthic communities on the continental shelf and upper slope of the Gulf of Alaska, Bering Sea, and Aleutian Islands support some of the largest and most important groundfish and crab fisheries in the world. Alaskan fisheries within the U.S. EEZ (3 to 200 nm offshore) are managed under five federal fishery management plans. Other important fisheries within 3 nm of shore are managed by the State of Alaska. Four types of bottom-contact gear are currently used that potentially affect coral habitat – otter trawls, longlines, pots, and scallop dredges. These fisheries are distributed from 27 m to about 1000 m, with most effort at depths shallower than

200 m (Stone 2006). The degree to which a particular gear affects coral habitat depends on its configuration (i.e., physical area of contact), operation (i.e., physical forces on the seafloor), spatial and temporal intensity of operation, seafloor bathymetry and substratum type, and the resilience of components of benthic communities (Table 2.3). Both direct and indirect effects from fishing activities on corals likely occur. Direct effects include removal as by-catch, damage caused by physical contact, and detachment from the seafloor and translocation to unsuitable habitat. Indirect effects include increased vulnerability to predation, especially for corals detached from the seafloor, and habitat alteration. Furthermore, there is some evidence that reproduction is suppressed in damaged shallow-water scleractinian corals due to a reallocation of energy reserves for tissue repair and regeneration (Wahle 1983) and similar effects may occur in deep non-scleractinian corals.

Disturbance from fishing activities is the greatest present threat to coral habitat in Alaska (Table 2.3). NMFS estimates that approximately 81.5 metric tons of coral were removed from the seafloor each year between 1997 and 1999 as commercial fisheries by-catch in Alaska (NMFS 2004). Approximately 91% of this by-catch occurs in the Aleutian Islands and Bering Sea and bottom trawls catch more than 87% of the total (NMFS 2004). Estimates of the amount of damaged or detached corals fishing activities leave behind on the seafloor are not available but may be substantial. In the central Aleutian Islands, disturbance to the seafloor from bottom-contact fishing gear was widespread and approximately 39% of the seafloor on video transects had been disturbed (Stone 2006). In total, 8.5% of the corals observed, mostly stylasterids and gorgonians, were damaged or otherwise disturbed (Stone 2006).

Bottom Trawls

Studies worldwide have determined that bottom trawling alters seafloor habitat and both directly and indirectly affects benthic communities (Jones 1992; Auster et al. 1996; Auster and Langton 1999; NRC 2002). In addition to removing target species, bottom trawling incidentally removes, displaces, or damages non-target species (Ball et al. 2000), changes the sedimentary properties of the seafloor (Churchill 1989), and reduces habitat complexity by physically altering biogenic structures, including corals, on the seafloor (Krieger 2001). Such changes can lead to population level effects on species of economic importance (Lindholm et al. 1999). Ultimately, the combination of effects may result in wide-scale ecosystem change (Gislason 1994; Goñi 1998). Directed studies on the effects of bottom trawling on deep coral habitat in Alaska have been limited to a few studies (Krieger 2001; Stone et al. 2005).

Bottom trawls have been extensively used in Alaskan fisheries since the 1930s. Bottom trawling has been prohibited east of 142º W longitude in the Gulf of Alaska (Figure 2.17A) including the inside waters of Southeast Alaska, since 1998 but intensive trawling occurred there prior to the closure. Bottom trawl effort elsewhere in the state is more continuously distributed (Figures 2.17B–2.17E). Small pockets of intense trawling for flatfish, Pacific cod, and Pacific ocean perch have occurred near Kodiak Island in the Gulf of Alaska (Figure 2.17B) and in the Aleutian Islands for Atka mackerel and Pacific ocean perch (Figures 2.17C and 2.17D). NMFS estimates that approximately 6.2 metric tons of coral are removed from the seafloor each year by bottom trawls in the Gulf of Alaska (NMFS 2004). Most of the Bering Sea has experienced some degree of exposure to bottom trawls (NMFS 2004) and several areas have been trawled on average more than five times per year (Figure 2.17E).

Most bottom trawling occurs on the continental shelf and upper slope at depths less than 500 m but some effort does occur to depths greater than 1000 m. Trawling occurs over a wide range of habitats depending on targeted species and does occur in areas of coral abundance. Total width of the trawl system while fishing may reach 110 m, but the area of the seafloor and associated epifauna contacted by the gear depends on the design of the otter boards and configuration of protective gear on other system components (Stone et al. 2005). Bottom trawling is a major threat to coral habitat because the area of seafloor contacted per haul is relatively large, the forces on the seafloor are substantial, and the spatial distribution of fishing is extensive (Table 2.3). Areas of the seafloor composed mostly of bedrock and boulders, and with irregular and steep bathymetry, are infrequently trawled due to the risk of damaged and lost gear. Such areas often support rich coral habitat and may serve as

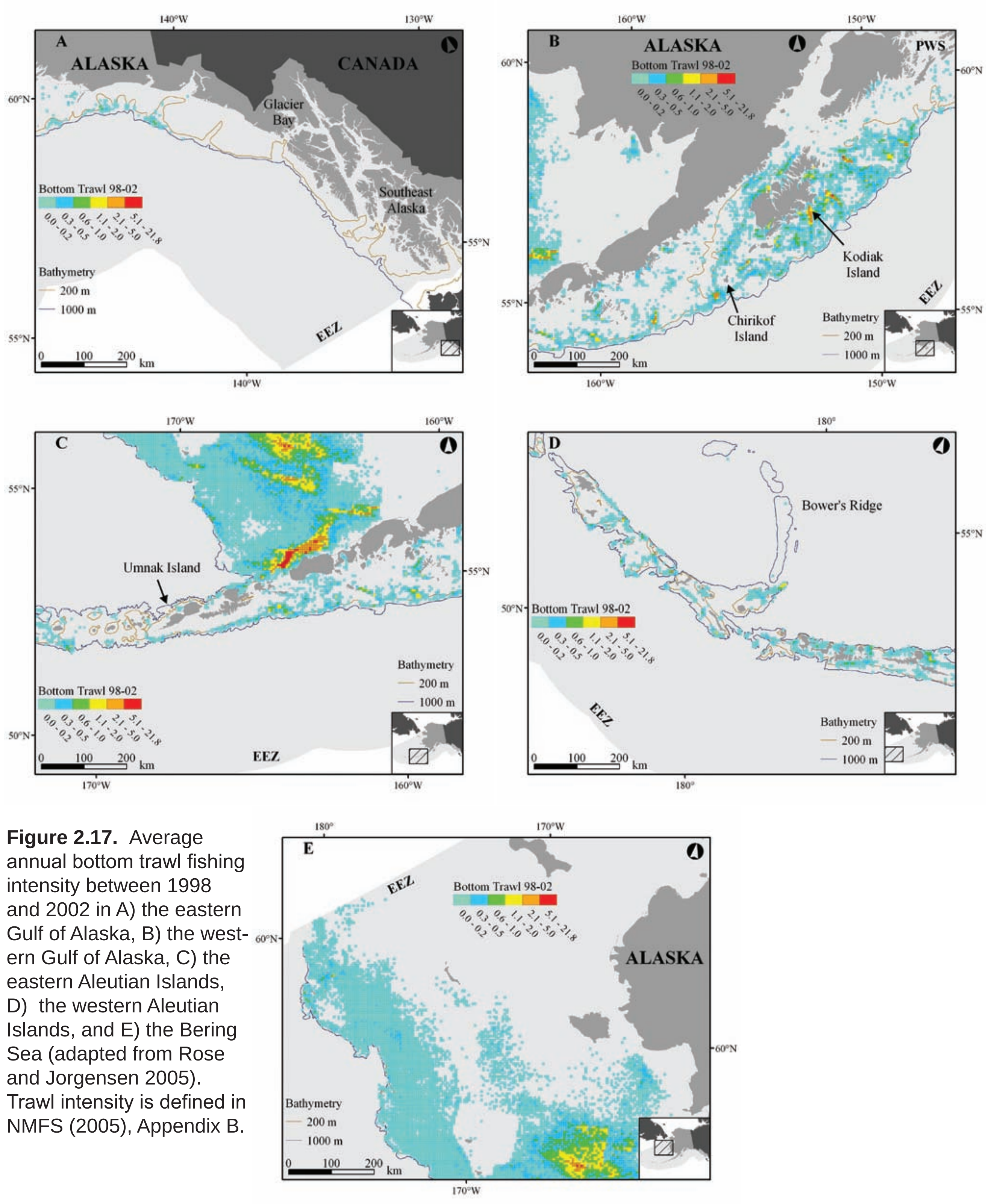

Figure 2.17. Average annual bottom trawl fishing intensity between 1998 and 2002 in A) the eastern Gulf of Alaska, B) the western Gulf of Alaska, C) the eastern Aleutian Islands, D) the western Aleutian Islands, and E) the Bering Sea (adapted from Rose and Jorgensen 2005). Trawl intensity is defined in NMFS (2005), Appendix B.

de facto sanctuaries from trawl disturbance.

Mid-water Trawls

Mid-water or pelagic trawls are modified bottom trawls (otter trawls) used to harvest groundfish near but not on the seafloor. Mid-water trawls are used exclusively to catch walleye pollock (*Theragra chalcogramma*) in the Bering Sea and are also used in Gulf of Alaska fisheries (see www.net-sys.com/trawlnets.htm for extensive descriptions of the various gear used in Alaskan waters). By regulation, the use of protective gear on the footrope is not allowed in an effort to discourage direct contact with the seafloor (NMFS

2004). However, the capture of sedentary benthic species with pelagic trawls is clear evidence that the gear does make at least occasional contact with the seafloor. Overall, pelagic trawls likely have little effect on deep coral habitat in Alaska since they are seldom fished on-bottom and typically in areas with minimal coral habitat (Table 2.3).

Gill Nets

Gill nets are used to harvest Pacific salmon in estuarine waters of Alaska but are not a threat to deep coral habitat because they are not used in areas known to support corals and seldom make contact with the seafloor.

Table 2.3. Potential effects of fishing gears on deep coral habitat in Alaska.

Gear Type	Severity of effects	Extent of effects	Geographic extent of use	Overlap of use with coral habitat	Overall rating of gear effects
Otter trawls	High	High	High	Medium	High
Mid-water trawls	Low	Low	Medium	Low	Low
Demersal longlines	Medium	Low	High	Medium	Medium
Single-set pots	Low	Medium	Medium	Low	Low
Longline pots	High	Medium	Low	Medium	Medium
Scallop dredges	Medium	Low	Low	Low	Low

Bottom Longlines

Longlines are used extensively throughout Alaskan waters to catch sablefish, Pacific halibut, Pacific cod, and several species of rockfish to a depth of at least 1000 m (Figures 2.18A-2.18E). Bottom (or demersal) longline systems consist of a mainline to which are attached 1000s of leaders and hooks (gangions), anchors, and buoyed lines. Mainlines often stretch 20 km or more across the seafloor and are often weighted in areas of rough bathymetry or strong currents. Both ends of the mainline are weighted with anchors and buoyed to the surface. No directed studies have been undertaken to study the effects of longlines on benthic habitat in Alaska. Longlines are thought to cause less of an effect on benthic communities than mobile fishing gear, but by-catch data and limited *in situ* observations clearly indicate that a significant interaction with coral habitat exists. Longlines are fished extensively in areas of known coral abundance and by-catch of corals is common in some areas. For example, corals, most notably *Primnoa*, were caught on 0.1% of the hooks (619 of 541,350) fished during the 1998 NMFS longline surveys in the Gulf of Alaska and Aleutian Islands (Krieger 2001). Longlines may entangle or hook corals during retrieval (High 1998), while fish attempt to escape during hooking (R. Stone, personal observations), and dislodge or damage corals from straining shear during retrieval (Stone 2006). Derelict longline gear has been observed entangled in *Primnoa* colonies in eastern Gulf of Alaska thickets (R. Stone, personal observations) and other gorgonians in Aleutian Island coral gardens (Stone 2006).

A small amount of longline fishing has occurred on Gulf of Alaska seamounts as evidenced by the recapture of tagged sablefish there (Maloney 2004). Sablefish tagged by NMFS as part of a stock assessment survey have been recovered by fishermen on Pratt, Surveyor, Murray, Durgin, and Quinn seamounts in the Gulf of Alaska. Scientists believe that the effort on the seamounts has been minimal and has occurred opportunistically while fishermen transit by the seamounts.

Longlines pose a moderate threat to coral habitat in Alaska (Table 2.3). They are used extensively over a broad depth range (Figures 2.18A-2.18E) and in virtually all habitat types including those that are typically too rough for trawling. The area of the seafloor contacted during typical fishing operations is low but can be more extensive during gear retrieval in adverse weather conditions. Straining shear and entanglement are the major forces on coral habitat and the seafloor. Longlines are often set in areas of irregular bathymetry and large arborescent corals such as *Primnoa pacifica*, *Paragorgia arborea*, and black corals are the most at risk to disturbance.

Pots and Traps

Pots are used extensively throughout much of Alaska to catch both fish and crabs and are deployed differently depending on the target species. Pots are fished singularly for Pacific

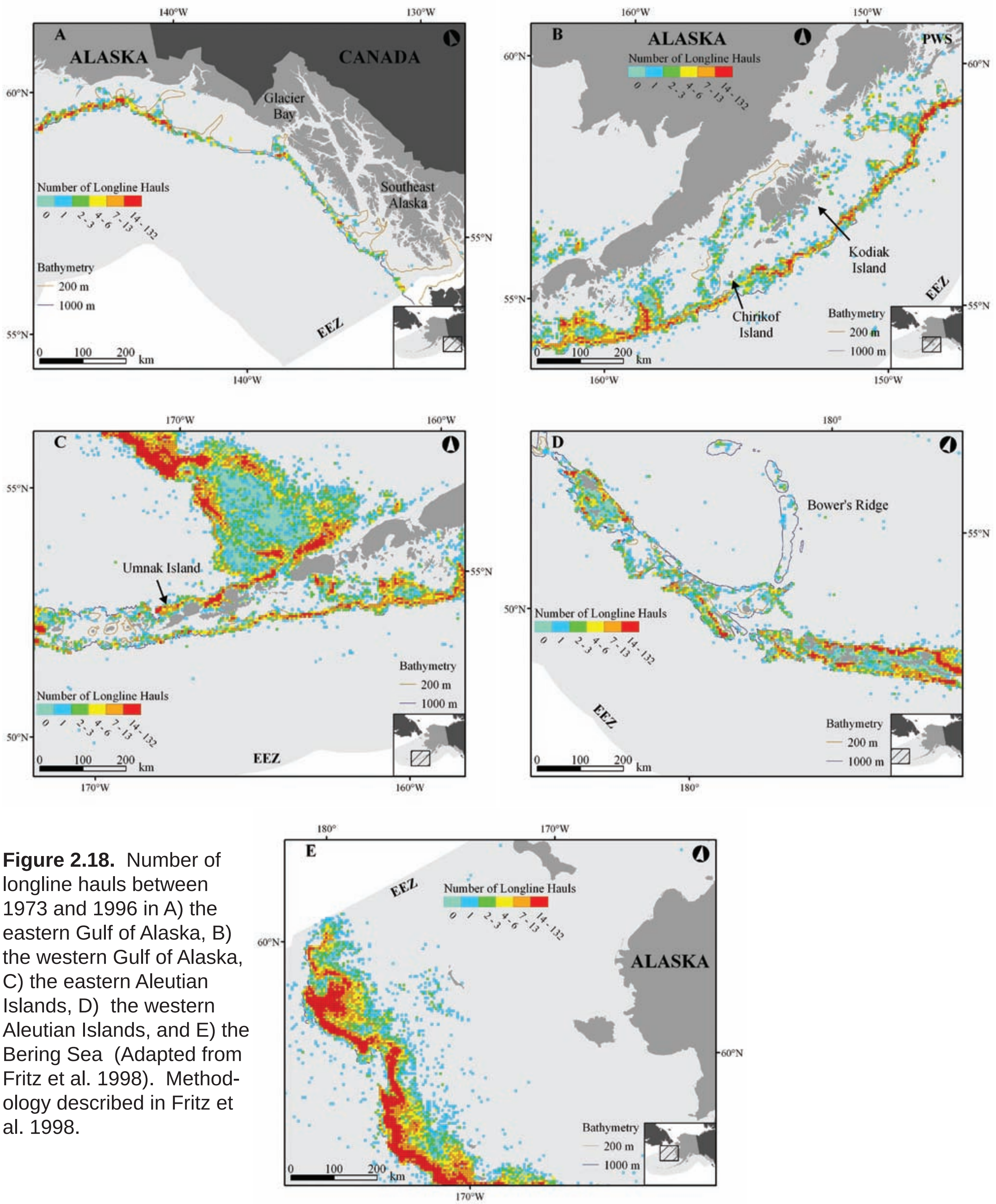

Figure 2.18. Number of longline hauls between 1973 and 1996 in A) the eastern Gulf of Alaska, B) the western Gulf of Alaska, C) the eastern Aleutian Islands, D) the western Aleutian Islands, and E) the Bering Sea (Adapted from Fritz et al. 1998). Methodology described in Fritz et al. 1998.

cod and sablefish in the Gulf of Alaska (Figures 2.19A and 2.19B) and additionally for Greenland turbot (*Reinhardtius hippoglossoides*) in the Aleutian Islands (Figures 2.19C and 2.19D) and Bering Sea (Figure 2.19E). Pot fishing is typically highly localized in these areas (Figures 2.19A-2.19E). Important fisheries with single pots for king crabs (*Paralithodes camtschaticus*, *P. platypus*, *Lithodes aequispina*), Tanner crabs (*Chionoecetes bairdi*), snow crabs (*Chionoecetes opilio*), and Dungeness crabs (*Cancer magister*) occur in the Gulf of Alaska and Bering Sea. Pot fisheries also occur for golden king crabs in the Aleutian Islands (Figures 2.19A and 2.19B). In

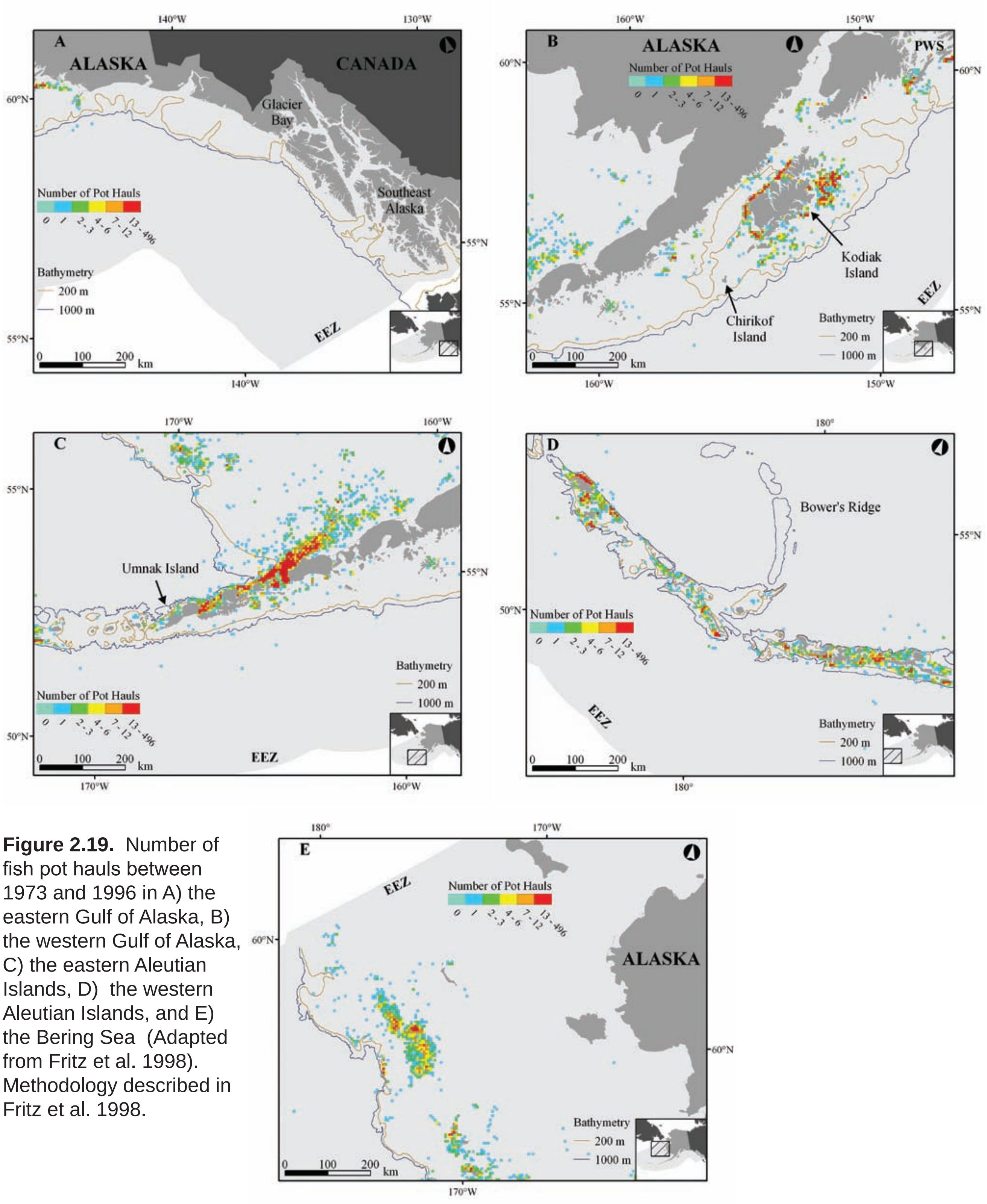

Figure 2.19. Number of fish pot hauls between 1973 and 1996 in A) the eastern Gulf of Alaska, B) the western Gulf of Alaska, C) the eastern Aleutian Islands, D) the western Aleutian Islands, and E) the Bering Sea (Adapted from Fritz et al. 1998). Methodology described in Fritz et al. 1998.

this fishery, however, pots are strung together in strings of 10 to 90 pots or more and total weight of the gear per string can exceed 30 metric tons. Pots are strung together with 1-inch or larger diameter polypropylene line and a single longline may stretch between 3 and 9 km. The fishery occurs at depths between 100 and 719 m and in a wide range of habitats on the slope, offshore banks, and offshore pinnacles that include rocky areas with irregular bathymetry.

No studies have been undertaken to study the effects of pot fishing on seafloor habitat in Alaska. Single pot fisheries likely have a minimal effect on

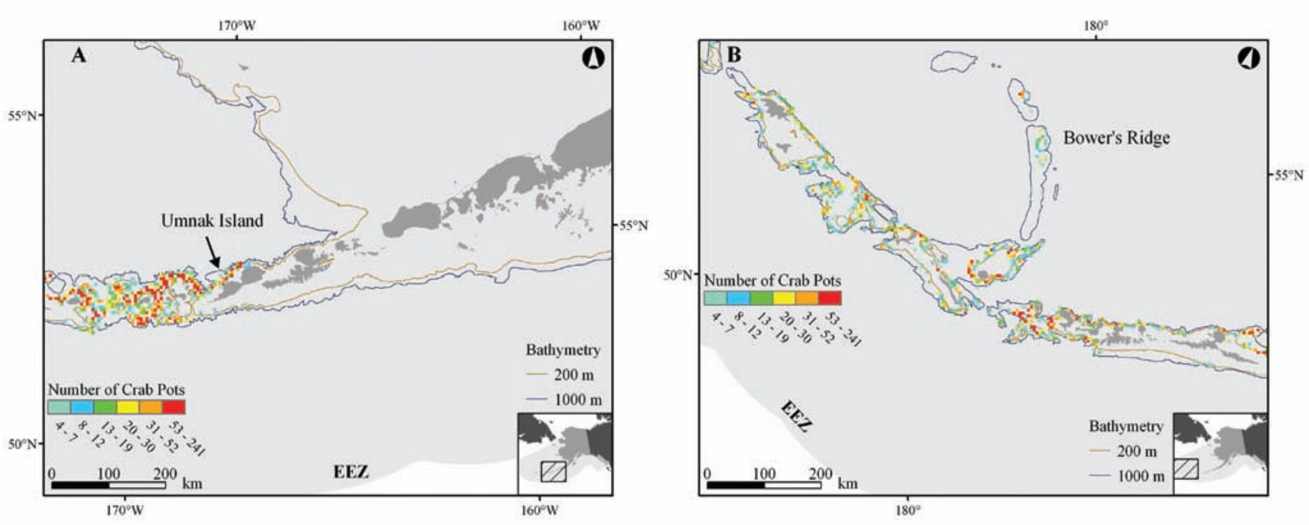

Figure 2.20. Number of observed crab pots during the golden king crab (*Lithodes aequispina*) fishery between 2001 and 2004 in A) the eastern Aleutian Islands and B) the western Aleutian Islands. Each area rectangle measures 0.05º latitude by 0.1º longitude. Source data: Alaska Department of Fish and Game.

coral habitat since they generally occur in soft-sediment areas with minimal coral habitat and because a relatively small area of the seafloor is contacted with the gear (Table 2.3). Pot longlines used in the Aleutian Island golden king crab fishery, however, have the potential to cause extensive damage to coral habitat (Table 2.3) since the spatial distribution of fishing is extensive in some areas of high coral abundance (Figures 2.20A and 2.20B). Depending on how the gear is retrieved, the area of seafloor contacted may be relatively large and the forces on the seafloor may be substantial. The gear is retrieved in a manner to minimize drag on the seafloor due to the strength limitations of the longline; however, under certain conditions the gear can be dragged like a plough across the seafloor. This situation can occur in areas of steep bathymetry and when strong winds and currents dictate that fishing vessels retrieve gear while being forced away from it. At one site in the central Aleutian Islands where disturbance from this gear was observed with the submersible *Delta* (Figure 2.21), the seafloor was scoured to bare substrate along 17 strips (Stone 2006). Aleutian Island coral gardens are at high risk to disturbance from this fishery.

Figure 2.21. Coral habitat can be fragmented by fishing gear as evidenced by this small patch of coral in the path of heavy disturbance. A small bubblegum coral (*Paragorgia arborea*), soft coral (*Anthomastus* sp.), stoloniferan coral (*Clavularia* sp.), hydrocorals, demosponges, and a sea anemone reside at the edge of a path littered with hydrocoral skeletons. Photo credit: R. Stone, NOAA Fisheries.

Scallop Dredges

A small but important fishery has occurred for the weathervane scallop *Patinopecten caurinus* in the Gulf of Alaska and Bering Sea since 1967 (Shirley and Kruse 1995). The fishery occurs in relatively well-defined areas of unconsolidated soft sediments on the continental shelf and at depths between 60 and 140 m (Turk 2001; Barnhart 2003). Scallop dredges are dragged along the seafloor and designed to dig into the top layer of sediment. Dredges have a maximum width of 4.6 m. No directed research on the effects of scallop dredges on coral habitat has been undertaken in Alaska. Overlap does occur between the fishery and the known distribution of pennatulaceans, including ecologically important groves of *Halipteris willemoesi* in the central Gulf of Alaska (Masuda and Stone 2003). With the exception of pennatulacean groves, scallop dredges pose a minimal threat to coral habitat at the present time (Table 2.3). The spatial distribution of fishing is small and the area of the seafloor contacted per tow is relatively small. While the gear is intrusive, it is generally used in soft-sediment areas where coral abundance is low. Groves of pennatulaceans in the Gulf of Alaska are most at risk to disturbance from scallop dredges.

Effects of Other Human Activities

Oil and Gas Exploration and Extraction

Offshore oil and gas operations in Alaska include exploration, development, and production activities (NMFS 2005). Most of these activities presently occur in Cook Inlet in the Gulf of Alaska and on the North Slope (Beaufort and Chukchi Seas)—areas of Alaska that do not support significant deep coral communities. Disturbances from these activities that may affect coral habitat include physical alterations to habitat, waste discharges (well drilling cuttings and muds), and oil spills. Cimberg et al. (1981) discuss the potential effects of oil and gas development on deep corals in Alaska. They concluded that Alaskan corals are unlikely to suffer adverse effects from oil and gas development, because most of the known deep coral distributions do not occur in lease areas and areas where platforms will be placed. They further conclude that the most physiologically sensitive life history stage of deep corals, the planula larval stage, is brief and demersal, and therefore unlikely to be affected by oil spills (Cimberg et al. 1981). No directed research has been undertaken to study the effects of oil toxicity on any life history stage of deep corals found in Alaska. The potential for effects from these activities on coral habitat is likely to increase in the future as the world's demand for oil and gas products continues to increase.

Deployment Of Petroleum Pipelines And Communication Cables

Cook Inlet is the only area of the state where petroleum pipelines (specifically crude oil) have been deployed in benthic marine habitats. Fourteen pipelines totaling 141 km in length were deployed on the seafloor of Cook Inlet between 1965 and 1986 (Robertson 2000). Eight state and federal agencies have regulatory authority over pipelines in Cook Inlet. Accidental spills have occurred in the past and are likely to occur in the future as many of the pipelines reach the end of their expected life span (Robertson 2000). The benthic marine life in the immediate area of the pipelines has not been inventoried but the region is not known to support abundant or diverse coral resources.

Numerous communication cables have been deployed on the ocean floor throughout Alaskan waters since 1900. Thousands of kilometers of cables stretch along the seafloor between Alaskan communities and ports in Washington and Oregon. Cables have been deployed from the shoreline down to depths of 7000 m. There are no known regulations governing the placement of submarine cables but their locations are accurately mapped so that potential interactions with other seafloor uses (e.g., fishing) can be avoided. There are no known reports of cable deployments directly affecting coral habitat although there is some likelihood that cables have been placed in coral habitat, especially in the Aleutian Islands. Cables are typically laid on the seafloor where they remain exposed but may be buried using specially designed ploughs in areas where bottom fishing and other seafloor uses occur. In areas where cables are exposed they may provide attachment substrates for corals and other emergent epifauna and may therefore provide a known time-line for studies of recruitment and subsequent growth of emergent epifauna that settle on them (Levings and McDaniel 1974). No such studies have been conducted yet in Alaska but clearly the potential exists to use submarine cable deployments to gain insights into coral habitat recovery rates. Deployment of communication cables is presently a minimal threat to deep coral ecosystems in Alaska given the very small area of the seafloor that is contacted by them.

Pollution - Point-source Discharges

Point-source discharges that occur in coastal marine areas of Alaska have little potential to affect deep coral habitat. Coral habitat is sparse in coastal areas of Alaska where point-source discharges occur or are expected to occur in the near future but a few coastal areas near municipalities do support groves of pennatulaceans. The greatest threat to coral habitat from point-source discharges is the introduction of large volumes of untreated sewage and chlorine. Sewage discharge causes organic nutrient enrichment of receiving waters, rapid increases in biological production, and eutrophication through depletion of dissolved oxygen (Tomascik et al. 1997). High concentrations of phosphates in effluent may also cause algal blooms that are lethal to corals (Alcolado 1998). Chlorine is toxic to marine life, and chlorinated sewage effluent may subject marine biota, including octocorals, to either single-event acute exposures or to chronic exposures (Tomascik et al. 1997).

Fish Processing Waste

In Alaska, seafood-processing facilities are located both on shore and at sea onboard processing vessels. Coral habitat is sparse in coastal areas of Alaska where seafood-processing discharges occur and concerns to coral habitat there would be similar to those for point-source discharges. At-sea processors would have little effect on deep coral habitat unless they routinely discharged waste in areas of high coral abundance.

Harvest of Precious Corals

A directed fishery for precious corals never developed in Alaska despite the fact that several species have potential commercial value as jewelry (Cimberg et al. 1981). Corals found in Alaska with potential commercial value include *Primnoa pacifica*, *Primnoa wingi*, bamboo corals (Family Isididae), black corals, and a single species of precious red coral (Family Coralliidae) reported from Patton Seamount in the Gulf of Alaska (A. Baco-Taylor, WHOI, pers. comm.). However, many corals that are collected as by-catch, particularly *P. pacifica*, bamboo corals, and stylasterids, are often retained by fishermen as souvenirs and curios.

Mineral Mining

Mineral mining operations in Alaska have been limited to offshore placer mining for gold and barite off the coast of Nome in Norton Sound (northern Bering Sea) and at a single location near Petersburg in Southeast Alaska (Conwell 1976). Mineral mining activities could potentially affect deep coral habitat through increased sedimentation and turbidity near the seafloor but are unlikely to occur in areas of coral abundance in the near future.

Climate Change

Climatic regime shifts and cyclic environmental fluctuations associated with Pacific Decadal Oscillations, El Niño/Southern Oscillation Climate and La Nina events have had documented effects on oceanographic and biological processes in the North Pacific Ocean. Effects on corals of this interannual to decadal variability have not been reported. Long-term climatic change due to global warming could affect seawater temperature, salinity, density, sea level, and ambient light levels especially in shallow and nearshore waters. None of these changes is expected to cause direct mortality of deep corals or significantly alter their geographic or depth distribution but effects on growth rates and food supply (i.e., phytoplankton) are possible.

Increases in atmospheric carbon dioxide caused by manmade emissions have been linked to decreases in oceanic pH (Caldeira and Wickett 2003). Decreases in oceanic pH and resulting decreases in calcium carbonate saturation state and calcification could have devastating effects on marine organisms dependent on the extraction of calcium carbonate from seawater for skeletal building (Kleypas et al. 1999; Guinotte et al. 2006). Zooxanthellate corals in shallow waters will experience decreasing aragonite saturation states that could negatively affect their calcification rates and the stability of reef ecosystems (Guinotte et al. 2003). Numerous studies have shown substantial decreases in calcification rates (>40%) with relatively modest decreases in aragonite saturation state (Langdon et al. 2003; Langdon and Atkinson 2005). Some evidence suggests that deep-sea biota may be sensitive to changes in pH (Seibel and Walsh 2001; Guinotte et al., 2006; Roberts et al., 2006). Mounting evidence suggests that if CO_2 emissions continue as projected, undersaturated regions will develop in the sub-arctic and polar regions of Alaska by the end of the 21st century (Orr et al. 2005; Kleypas et al. 2006; Guinotte et al. 2006). Scleractinian corals would be most affected by this development, but are not important structure-forming corals in Alaskan waters. Octocorals, stylasterids and pennatulaceans however, are important structure-forming components of benthic ecosystems in Alaskan waters and will likely be affected by ocean acidification. The sclerites of octocorals are calcitic, but the axes may be composed of calcite, aragonite, or amorphous carbonate hydroxylapatite (Bayer and Macintyre 2001). The calcite saturation horizon, along with the aragonite saturation horizon, is moving to shallower depths over time (Feely et al. 2004), which could affect all corals in Alaska that use calcite to build skeletal tissue.

Invasive Species

The introduction of invasive species to Alaskan waters is a real threat and the State of Alaska has developed an Aquatic Nuisance Species Management Plan to prevent introductions and identify and respond to threats (ADF&G 2002). Ballast water discharges from ships and barges are the single largest potential source of invasive species in Alaska. For example, tankers arriving from domestic ports at Port Valdez, Prince William Sound, release the third largest volume of ballast water of all U.S. ports (ADF&G 2002). Tankers arriving from foreign ports are required to exchange ballast water at sea (in waters at least 2000 m deep). The potential for introductions in coastal Alaska and the Aleutian Islands in particular is high given the high volume of ship traffic from ports around the world.

To date, the introduction of invasive species has been largely limited to a few species of freshwater fish and aquatic plants. There are no known invasive species of corals or predators of corals in Alaskan waters although the threat of introduction exists. The threat of introduction may increase if more favorable oceanic conditions related to climatic change develop in the future.

VIII. MANAGEMENT OF FISHERY RESOURCES AND HABITATS

The North Pacific Fishery Management Council (NPFMC) manages the fishery resources of Alaska with five Fishery Management Plans (FMPs). The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) mandates that FMPs must include a provision to describe and identify essential fish habitat (EFH) for each fishery, minimize to the extent practicable adverse effects on such habitat caused by fishing, and identify other actions to encourage the conservation and enhancement of such habitat. EFH has been broadly defined by the Act to include “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.” Deep coral habitat has been identified as EFH for some groundfish species (Witherell and Coon 2001) and several areas of Alaska have recently been designated as Habitat Areas of Particular Concern (HAPCs) and are presently afforded some protection from disturbance by fishing activities (described below). The Minerals Management Service (US Department of the Interior) oversees petroleum and mineral resource development in the offshore waters of the U.S. EEZ and implements studies designed to predict the effects of resource development on the marine ecosystem including deep coral habitat.

Seafloor Mapping

Approximately 46,710 km^2 of seafloor habitat has been mapped in the Alaska region using multibeam sonar technology (Table 2.4). These efforts have been piecemealed together by several agencies including NMFS, Alaska Deparment of Fish and Game (ADF&G), National Park Service (NPS), University of Alaska Fairbanks, and Oregon State University. Additionally, about 27,780 km^2 of seafloor has been mapped by NOAA’s National Ocean Service (NOS) since 1994 for navigational purposes. No coordinated plan to map the seafloor within the EEZ currently exists and mapping efforts to date have been scattered from Southeast Alaska through the Aleutian Islands including some of the seamounts within the EEZ. Mapping has included 4,220 km^2 and 28,280 km^2 of seafloor on Gulf of Alaska shelf and slope habitats and Gulf of Alaska seamounts, respectively. An additional 14,150 km^2 of seafloor has recently been mapped in the Aleutian Islands.

While the purpose of the seamount and some of the Aleutian Island mapping efforts have been strictly to support detailed studies on deep coral habitat, most of the mapping efforts to date have been in support of studies on essential fisheries habitat and geological processes. Additional goals of these studies have been to determine the effects of fishing on benthic habitat, fish stock assessments, understanding basic ecological processes, and life history studies of benthic organisms (e.g., Shotwell et al. in press; O’Connell et al. in press).

Several of the mapping efforts have included the collection and subsequent interpretation of backscatter data and the detailed classification of seafloor habitats using the methods of Greene et al. (1999). Direct observations of the seafloor with occupied submersibles, ROVs, or towed cameras have been used to ground-truth habitat types and provide fine-scale resolution of habitat features. One goal of the Aleutian Island studies (see http://www.nprb.org/research/res_2003_projects_listing.htm) is to develop a model to predict where deep coral habitat is located throughout the region. Mapped areas were systematically

Table 2.4. Areas of Alaska that have been mapped with modern multibeam sonar technology. AI = Aleutian Islands, GOA = Gulf of Alaska, SM = seamounts, UAF = University of Alaska Fairbanks, NMFS = National Marine Fisheries Service, ADFG = Alaska Department of Fish and Game, OSU = Oregon State University, NPS = National Park Service.

Region	Name of area	Agency	Depth range (m)	Coral presence	Area (km^2)
GOA	Hazy Islands	ADFG	50-300	Yes	390
GOA	Cape Ommaney	ADFG, NMFS	30-300	Yes	275
GOA	Glacier Bay National Park	NPS	10-410	Yes	62
GOA	Fairweather Ground	ADFG	23-192	Yes	280
GOA	Yakutat Bay	ADFG	15-50	Unknown	20
GOA	Yakutat Bay	ADFG	15-50	Unknown	20
GOA	South Yakutat	NMFS	190-1045	Unknown	372
GOA	Pamplona Spur	NMFS	120-940	Yes	162
GOA	Portlock Bank	NMFS	100-750	Yes	790
GOA	Albatross Bank, Snakehead	NMFS	60-810	Yes	310
GOA	Albatross Bank, 8-fathom pinnacle	NMFS, NOS	20-716	No	17
GOA	Albatross Bank, 49-fathom pinnacle	NMFS	80-800	Unknown	32
GOA	Chirikof	UAF	100-600	Unknown	1,550
GOA, SM	Seamounts 2002	UAF, OSU	?	Yes	?
GOA, SM	Seamounts 2004	UAF, OSU	?	Yes	14,081
GOA, SM	Transit between seamounts	UAF, OSU	?	Unknown	9,000
GOA, SM	Derickson Seamount	UAF, OSU	2750-6800	Yes	5,200
AI	Akutan	UAF	78-482	Unknown	27
AI	Bogoslof	UAF	20-820	Unknown	28
AI	RV *Revelle* transit	UAF	90-4200	Yes	11,341
AI	Samalga Island, North	NMFS	107-323	Yes	11
AI	Samalga Island, South	NMFS	120-150	Yes	9
AI	Islands of Four Mountains, North	NMFS	144-223	Yes	13
AI	Islands of Four Mountains, South	NMFS	88-204	Yes	12
AI	Islands of Four Mountains, West	NMFS	116-218	Yes	11
AI	Aleutian Corals	NMFS	100-3000	Yes	2,697
AI	Track Lines	NMFS	30-4000	Yes	NA
Total					**46,710**

selected so that results can be extrapolated to unmapped areas. Habitats within the mapped areas are currently being classified through interpretation of the bathymetric and backscatter data. Submersible and ROV observations are being used to ground-truth the habitat types, map coral observations, and ultimately to provide data on coral densities relative to mapped habitat features.

Ongoing Research

Research activities in 2006 focused on completing taxonomic, genetic, and reproductive ecology analyses on more than 400 coral specimens collected during the 2003-04 Aleutian Island studies and 140 coral specimens collected during the 2004 Gulf of Alaska seamount cruise. Additionally, detailed examination of video footage collected from submersibles and ROVs during these studiesis underway and willto provide fine-scale data on coral distribution, habitat characteristics, species associations, and disturbance from both human and natural causes.

The submersible *Delta* was used in 2005 to delineate the extent of *Primnoa* thickets in two areas of the eastern Gulf of Alaska (Fairweather Ground and Cape Ommaney; Figure 2.22). The two areas were established as HAPCs by NMFS in July 2006 and the use of all bottom-contact fishing gear is now prohibited in those areas. The purpose of the research was to provide detailed data on the distribution of *Primnoa* in the areas so that the efficacy of the closures to protect the thickets from incidental disturbance can be predicted. Additional objectives of the research are to assess the present condition of the thickets, examine the fine-scale use of the coral habitat by FMP species, and collect specimens for taxonomic identification. A third site in Dixon Entrance near the maritime boundary with Canada was also investigated to determine if the *Primnoa* thickets reported from that region (Krieger 2001) warrant designation as a HAPC. The thickets in that region appear to be located in deeper water and in a region where both the U.S. and Canada claim jurisdiction. A joint research cruise by both governments may be planned in the future to examine coral habitat in that region.

A two-year study to examine shallow-water populations of *Primnoa pacifica* in Glacier Bay National Park was completed in April 2005. Populations of *Primnoa* were discovered in 2004 along bedrock walls recently exposed by retreating glaciers (Figure 2.23). The study is investigating the role of oceanographic processes in coral depth distribution and the potential use of an accurate deglaciation record to validate estimated growth rates for the species (Stone et al. in preparation). Thriving populations of *Primnoa* were discovered in two additional glacial fjords in Holkham Bay, Southeast Alaska during a research cruise in 2006. Samples were collected from 80 colonies from four spatially distinct "populations" during a second cruise to the fjords in 2007. Those samples will be used to develop microsatellite genetic markers to examine the population structure of *Primnoa* in the fjords and to address questions regarding larval dispersal and gene flow.

Planned or Anticipated Activities

No directed research or mapping activities are planned at the present time due to limited funding and personnel support. Several important areas of deep coral research remain a high priority for the region (discussed below) and those will be addressed as funding and support becomes available in the future.

North Pacific Fishery Management Council

The North Pacific Fishery Management Council has responsibility for developing fishery management plans for the nation's groundfish resources in the EEZ of the Alaska region and oversees the implementation of measures to conserve and enhance essential fish habitat for those resources. Since 1987, 1,107,890 km^2 of seafloor habitat in the Bering Sea and Aleutian Islands has been afforded some protection from fishing activities (Figure 2.22). An additional 202,380 km^2 of seafloor habitat has been afforded some level of protection in the Gulf of Alaska (summarized in NMFS 2004). Most area closures are for specific gear types only, others are seasonal, and some closures go into effect only when a species by-catch cap has been reached. Year-round closures to trawl gear exist in both the Bering Sea and Gulf of Alaska to protect important crab habitat. Year-round closures also exist around Steller sea lion rookeries to protect forage species. A single area, the 8.1 km^2 Edgecumbe Pinnacles Marine Reserve (also known as the Sitka Pinnacle Marine Reserve) in the eastern Gulf of Alaska, was established in 2000 as the only no-take groundfish reserve in the state. A

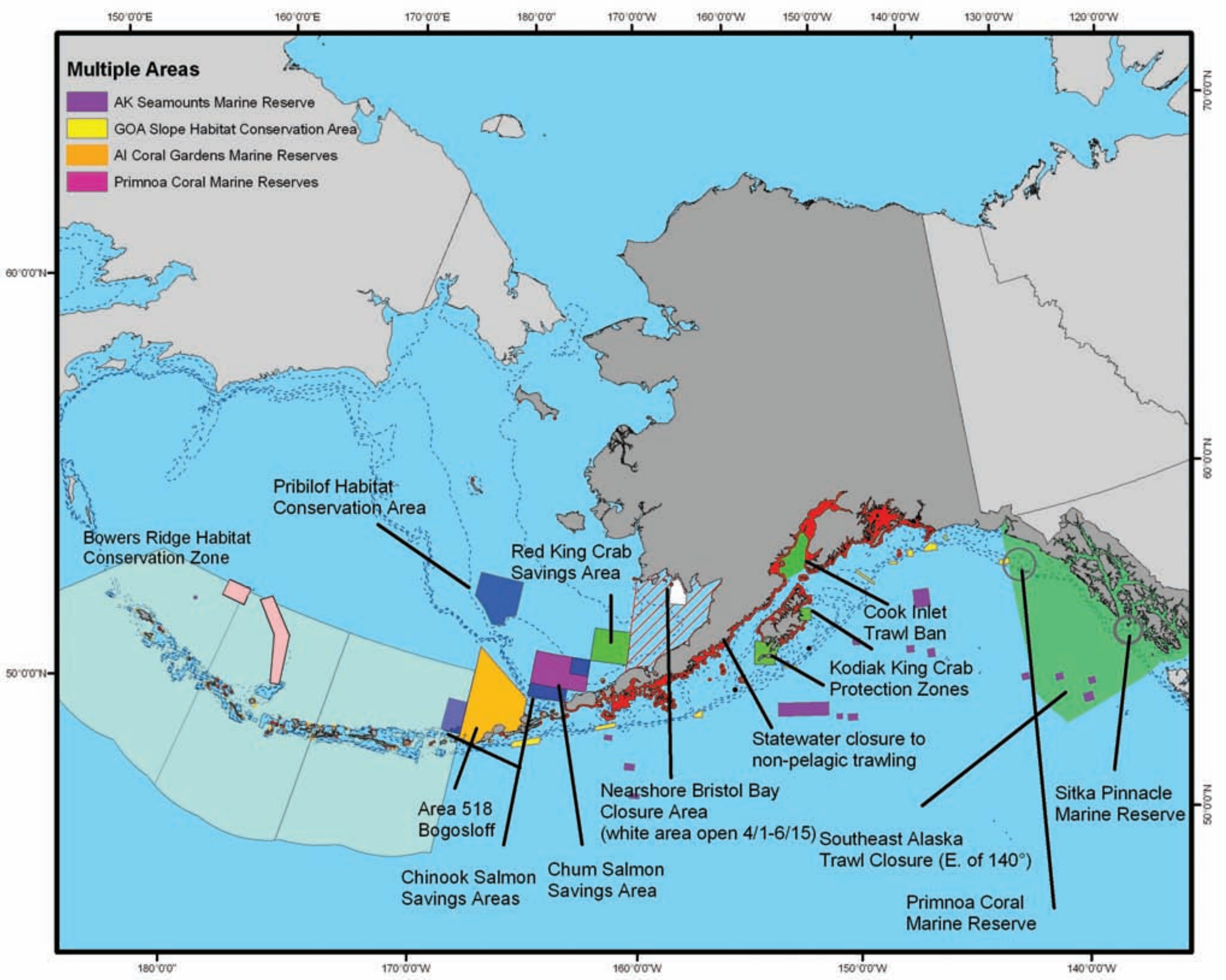

Figure 2.22. Areas of Alaska with some restrictions on fishing activities. Map credit: Cathy Coon, NPFMC.

comprehensive inventory and classification of Marine Protected Areas (MPAs) in Alaska and a brief history of their development is provided in Witherell and Woodby (2005).

In February 2005 the NPFMC voted unanimously to protect vast areas of seafloor habitat in the Gulf of Alaska and Aleutian Islands. NMFS approved the Record of Decision on the NPFMC essential fish habitat (EFH) environmental impact statement (EIS) containing these provisions on August 8, 2005 and the regulations were implemented in July 2006. The Aleutian Islands closures include a vast area (957, 361 km^2) of seafloor west of the Islands of Four Mountains (170° W) and includes nearly the entire EEZ in the region (Figure 2.24). The Aleutian Islands Habitat Conservation Area (AIHCA) is the largest bottom trawl closure in the U.S. and the first in the state directed at protecting sensitive deep coral habitat. Under the decision, areas that have been trawled in the past and have supported the highest groundfish catches will remain open (42,611 km^2), while largely unfished areas including Bowers Ridge in the Bering Sea, are closed to bottom trawling (Figure 2.24). Approximately 52% of the fishing grounds previously targeted by trawlers (defined as those habitats within the current depth range of trawl activities—1000 m depth), or about 100,000 km^2 of seafloor, are now closed to bottom trawling in the Aleutian Islands (Figure 2.24). The majority of the seafloor habitat within the closure has not yet been explored by scientists but much of it is deep abyssal plain that likely supports little deep coral habitat. Initial indications are that few species of commercial importance exist in these deep areas that would have put the habitat at risk to immediate or future trawling activities. Nonetheless, the closure effectively freezes the current footprint of trawling activities until scientists can determine the full scope of deep coral habitat and fisheries resources in the region. Perhaps the highlight of the AIHCA is the closure of six coral gardens (377 km^2 total) in the central Aleutian Islands where the use of all bottom-contact gear is now prohibited (Figure 2.24).

The NPFMC also voted to establish HAPCs in the Gulf of Alaska where the use of all bottom-contact fishing gear would be prohibited. These include five small areas (46 km^2 total) in the eastern Gulf of Alaska to protect dense thickets of red tree corals (*P. pacifica*), 7,155 km^2 of slope habitat and 16 seamounts (the majority in the Gulf of Alaska) to protect deep coral habitat (18,278 km^2 total).

Figure 2.23. *Primnoa pacifica* thrives in the cold, dark glacial fjords of Southeast Alaska. This colony, at a depth of only 18 m, provides a resting platform for a blue king crab (*Paralithodes platypus*). Photo credit: R. Stone, NOAA Fisheries.

Directed Harvest

In April 2000, the NPFMC introduced a regulation defining all corals as prohibited species (Witherell and Coon 2001). The regulation would have effectively prohibited the sale, barter or trade of corals but the measure was never adopted by the NPFMC since it would only apply to federally licensed groundfish vessels and fishermen. Rather than adopt a measure that would not have applied to all fishing vessels, the NPFMC relegated management authority to the State of Alaska under provisions of the MSFCMA. Section 306(a)(3)(C) of the MSFCMA gives authority to the State of Alaska to regulate fishing vessels in the EEZ, even if not registered with the State, if they are operating in a fishery for which there was no FMP in place on August 1, 1996. In 2003, the State of Alaska adopted a regulation (5 ACC 38.062e) that states that no permits will be issued to commercially harvest corals or sponges. This regulation applies to both state waters and those within the EEZ.

Minerals Management Service

Offshore drilling activities are regulated by the U. S. Department of the Interior's Minerals Management Service and their proposed plan for outer continental shelf (OCS) oil and gas leasing (2007 - 2012) includes two lease sales in the North Aleutian Basin. Offshore drilling in the OCS region of Alaska began in 1975 and since that time nearly 100 exploratory wells have been drilled. Twenty nine wells have been drilled in shallow-water (5 - 51 m depth) areas of the Beaufort Sea. Five wells have been drilled at depths between 42 and 46 m in the Chukchi Sea, 24 wells have been drilled in the Bering Sea Region (Norton Sound, Navarin Basin, and south of the Pribilof Islands) at depths between 11 and 165 m, and 25 wells have been drilled in the Gulf of Alaska including 13 in Cook Inlet at depths between 35

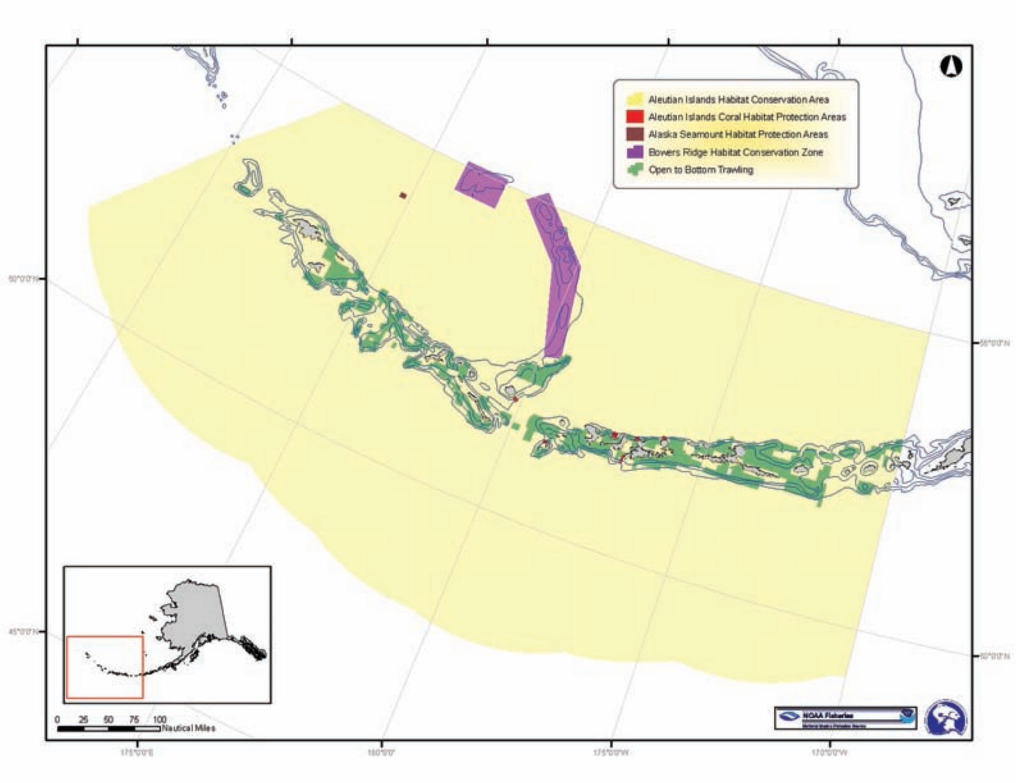

Figure 2.24. Closure areas in the Aleutian Islands, Alaska that were proposed by the North Pacific Fishery Management Council in February 2005 and approved by NOAA Fisheries in 2006. Map credt: Cathy Coon, NPFMC.

and 263 m. There are currently no regulations in place specifically to protect deep corals from these activities and most present drilling activities occur in areas not known to support abundant or diverse coral resources. In early 2007 however, the longstanding moratorium barring offshore oil and gas drilling in Bristol Bay and the southeastern Bering Sea was lifted by President Bush paving the way for oil and gas lease sales in this region of Alaska. While removal of the ban has caused the greatest concern over the potential effects offshore drilling may have on the area's rich stocks of salmon and groundfish, the area may also support important coral habitat, particularly beds of soft corals, that could be affected by any development in the region.

National Marine Sanctuaries

No National Marine Sanctuaries exist in Alaskan waters.

IX. REGIONAL PRIORITIES TO MANAGE AND CONSERVE DEEP CORAL COMMUNITIES

Directed research on deep coral habitat has been undertaken only during the past decade in the Alaska Region. Geographical areas known to support abundant and diverse deep corals, such as the Aleutian Islands and Gulf of Alaska seamounts, have been the first priority for exploration and specimen collection. While specimen collections and direct observations of deep corals in those areas will provide important foundation studies on coral ecology and systematics, many research priorities remain for the region.

Recently, NMFS recommended that the NPFMC pursue three courses of action regarding the effects of fishing on essential fish habitat in Alaska (NMFS 2005) and these apply directly to deep coral habitat:

1. The NPFMC and NMFS should continue to analyze how implementation of fisheries management measures affects seafloor habitats.
2. The NPFMC should continue to support research to improve scientific understanding of the effects of fishing on seafloor habitat, the ecological processes linking habitats and managed species, and the recovery rates of seafloor habitats disturbed by fishing gear.
3. The NPFMC should take specific precautionary management actions to avoid

additional disturbance to fragile seafloor habitats that may be especially slow to recover.

The third course of action recommended by NMFS has already been met to a large degree through the recent closure of vast areas of seafloor to fishing activities. These closures now provide an excellent opportunity to pursue the first and second courses of action to some degree. In support of these courses of action we have identified the following priorities for future deep coral research and conservation in the Alaska Region.

- **Research**

Studies on the growth rates and reproductive ecology from representative corals of the major taxonomic groups need to be undertaken to provide estimates of recovery rates for coral habitat. These data will provide a better understanding of the ability of species to recover from disturbance and recolonize areas set aside as mitigative measures such as HAPCs or MPAs. Growth rates are known for only three octocoral species that occur in Alaska (*Calcigorgia spiculifera*, *Halipteris willemoesi*, and *Primnoa* sp.) and range from approximately 5.8 mm yr^{-1} to 23.2 mm yr^{-1} (Stone and Wing 2002; Wilson et al. 2002; Andrews et al. 2002). Whether these rates encompass the full range of growth rates for other octocorals or for other taxonomic groups (e.g., antipatharians) is unknown. Additional growth rate studies are needed for representative species from each major structure forming taxonomic group and for those taxa that form single-species assemblages that provide important habitat in certain regions. The following taxa are excellent candidates for growth studies: 1) the gorgonians *Fanellia* spp., *Plumarella* spp., *Thouarella* spp., and *Keratoisis* spp. or *Isidella* spp., 2) the stylasterids *Stylaster cancellatus* and *S. campylecus*, 3) the antipatharians *Chrysopathes formosa* and *C. speciosa*, and 4) the true soft coral *Eunephthea rubiformis*. Studies on the reproductive ecology of deep corals have been limited to Aleutian Island stylasterids (Brooke and Stone in press) and a few species of Aleutian Island gorgonians (Anne Simpson, University of Maine, unpublished data). Reproductive ecology studies should be undertaken for *Primnoa* spp. and all of the taxa listed above.

Taxonomic studies need to be expanded so that accurate identifications of by-catch can be made in the field. Gorgonians, stylasterids, black corals, pennatulaceans, and true soft corals are abundant and important structure-forming corals in the Alaskan Region yet their taxonomy is still poorly understood despite the fact that extensive collections have now been made throughout much of the region. The taxonomy for 52 of the 141 unique taxa of deep corals (nearly 37%) documented from Alaska have not been accurately identified to species.

Studies on the effects of ocean acidification and oil toxicity on deep corals should be undertaken now. Ocean acidification could have serious consequences on deep corals in areas of the North Pacific Ocean where the aragonite and calcite saturation horizons are already quite shallow and predicted to become shallower in the near future (Guinotte et al. 2006). Studies should include monitoring shallow-water populations of the scleractinians *Javania borealis*, *Caryophyllia alaskensis*, and *Balanophyllia elegans* in the central Aleutian Islands (Stone 2006) and also laboratory manipulative experiments that subject cold water corals to the more acidic conditions they are likely to encounter in the coming decades. New deep-sea technology (e.g. free ocean CO_2 enrichment systems or FOCE systems) is currently being developed that will allow scientists to monitor calcification rates of corals *in situ* while carefully controlling and manipulating pH (Bill Kirkwood, Monterey Bay Aquarium Research Institute, pers. comm). When fully developed this technology will be a highly valuable tool for studying the effects of ocean acidification on deep corals in Alaska. Oil and gas exploration and extraction is likely to increase in the marine environment of Alaska in the near future. Laboratory manipulative experiments should be conducted to determine the toxicity effects of oil on both the adult and larval stages of deep corals. The soft coral, *Eunephthea rubiformis*, is an excellent candidate for such studies.

Studies on the effects of specific fishing gear types on coral habitat need to be undertaken so that we can better understand the effects of certain fisheries on coral habitat. Experiments on gear modifications to reduce coral by-catch and contact with the seafloor should be a high priority. Further studies need to be conducted on the use of coral habitat by managed groundfish species.

Limited research to date clearly indicates that many FMP species are associated with coral habitat but the nature of the associations is still unknown. Additional research is necessary to examine in detail how these species use coral habitat (i.e., to accomplish which life processes) so that estimates of changes to overall fisheries productivity can be made following disturbance.

Reconnaissance submersible dives should be undertaken in coral "hotspots" to assess their suitability as HAPCs. Coral hotspots include areas of abundant and diverse by-catch and areas known or suspected by scientists to support assemblages of gorgonians, pennatulaceans, and antipatharians. Hotspots include areas along the shelf and upper slope of the Gulf of Alaska where stock assessment surveys indicate the presence of *Primnoa* thickets and patches of bamboo corals and black corals. Other hotspots include several of the canyons on the Bering Sea shelf where survey by-catch records indicate the presence of *Primnoa* sp, *Paragorgia* sp., bamboo corals, and groves of pennatulaceans—the northernmost records for these corals in the North Pacific Ocean.

Reconnaissance submersible dives should also be made on areas of Bowers Bank in the Bering Sea that were recently closed to all bottom trawling as part of the recently established Aleutian Islands Habitat Conservation Area. The Bank is completely unexplored and is one of the few regions of Alaska that has received very little fishing pressure but is thought to contain extensive deep coral habitat based on its geographical proximity to the Aleutian Islands and Petrel Bank where rich coral habitat has been documented.

- **Seafloor mapping**

Multibeam mapping technology is very expensive (i.e., recent efforts in the Aleutian Islands were approximately $30,000 per day and on average about 80 km^2 could be mapped per day) and consequently only a fraction of 1% of the seafloor in the Alaska Region has been mapped to date. Some of the recent mapping effort has been in support of submersible operations with the directed coral studies. Other efforts have been in heavily fished areas in the Gulf of Alaska that do not support abundant coral resources but are important areas for the study of gear effects on seafloor habitat. Many areas of high coral abundance, based on by-catch records, have not been mapped and they should rate as a high priority for the limited funds available for that purpose. The coral hotspots listed above are a high priority for mapping.

- **Coral by-catch database**

Coral by-catch in fisheries and stock assessment surveys will continue to be an important data source in mapping Alaska's coral resources and interactions with fisheries. Databases for these surveys are well established and maintained and are a tremendous source of data (e.g., Heifetz 2002; Etnoyer and Morgan 2005). While the databases are currently in a usable format some restrictions regarding confidentiality do limit their usefulness at the present time. Fisheries observer databases could be greatly improved by including more precise locations of fishing effort and coral by-catch. Coral by-catch from the surveys is also a tremendous, and largely untapped, source of specimens for taxonomic, paleoclimatological, and ecological analyses. Specific collection requests for these purposes are occasionally accepted by the survey teams but little time is typically available for these purposes and proper identification of requested taxa are often difficult. Training in coral identification should be made available to all fisheries observers and the publication of additional field identification guides should be undertaken to facilitate these requests.

X. CONCLUSION

Deep corals are an important component of benthic ecosystems in Alaska. Highly varied submarine geology, persistent water currents, and plankton rich waters support at least 141 species from six major taxonomic groups. Deep corals have a broad geographical and depth distribution within the region. The Aleutian Islands support the highest diversity and abundance of corals in Alaskan waters but other subregions, such as the Gulf of Alaska and Bering Sea, support important single-species assemblages of gorgonians, pennatulaceans, and true soft corals. Many are important structure-forming species due to their large size, branching morphology, and patterns of distribution.

Fishing gear that contacts the seafloor is presently the single largest threat to coral habitat in Alaska. Evidence from research submersible observations and coral by-catch data collected during fisheries and stock assessment surveys indicate that interactions between coral habitat and current fisheries occur in many areas. The NPFMC and NMFS have taken significant steps to address this interaction by recently implementing extensive closures specifically to protect coral habitat from disturbance caused by fishing activities.

Most of the commercial species currently harvested in Alaska (approximately 85% of all FMP species or species groups) spend all or part of their life cycle in deep habitat where corals are potentially found. As the world population continues to grow and the demand for seafood increases in the future, conservation of Alaska's deep coral resources will be a major challenge for managers striving to maintain sustainable fisheries. NOAA recognizes the value of both shallow and deep coral habitat conservation in that endeavor and has listed it as one of nine programs within the Ecosystems goal in its strategic plan—the only taxa explicitly listed in the Strategic Plan and the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 mandates continued research, mapping, and protection of deep coral communities.

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Appendix 2.1. Geographical distribution of corals in Alaska waters. EG = eastern Gulf of Alaska, WG = western Gulf of Alaska, AI = Aleutian Islands, BS = Bering Sea, SM = seamounts. ● = documented, ○ = not documented. Adapted from Heifetz et al. (2005).

Taxa	EG	WG	AI	BS	SM
Phylum Cnidaria, Class Anthozoa, Order Scleractinia (Stony Corals)	●	●	●	●	●
Balanophyllia elegans	●	●	●	○	○
Caryophyllia alaskensis	●	●	●	○	○
Caryophyllia arnoldi	●	●	●	○	●
Crispatotrochus foxi	○	○	●	○	○
Flabellum sp.	○	○	●	○	○
Fungiacyathus marenzelleri	○	○	●	○	○
Fungiacyathus sp. A	○	○	○	○	●
Javania borealis	○	●	●	○	●
Javania cailleti	●	●	●	○	○
Leptopenus discus	○	○	●	○	○
Paracyathus sp.	○	○	●	○	○
Order Antipatharia (Black Corals)	●	●	●	●	●
Bathypathes alternata	●	○	○	○	○
Bathypathes patula	●	○	○	○	●
Bathypathes sp. A	●	○	○	○	●
Bathypathes sp. B	○	○	○	○	●
Chrysopathes formosa	●	○	○	○	○
Chrysopathes speciosa	●	○	○	○	○
Dendrobathypathes boutillieri	●	○	●	○	●
Heliopathes pacifica	○	○	○	○	●
Lillipathes lilliei	●	○	○	○	○
Lillipathes wingi	●	○	○	○	●
Parantipathes sp.	●	○	●	○	●
Stichopathes sp.	○	○	○	○	●
Trissopathes pseudotristicha	○	○	●	○	●
Trissopathes tetracrada	○	○	○	○	●
Subclass Octocorallia, Order Alcyonacea, Suborder Alcyoniia (True Soft Corals)	●	●	●	●	●
Alcyonium sp.	○	○	●	○	○
Anthomastus japonicus	○	○	●	●	○
Anthomastus cf. *japonicus*	○	○	●	○	○
Anthomastus ritteri	●	●	●	○	○
Anthomastus sp. A	○	○	●	○	●
Anthothela cf. *grandiflora*	○	○	●	○	○
Eunephthea rubiformis	●	●	●	●	○
Eunephthea sp. A	○	○	●	○	○
cf. *Eunephthea*	○	○	●	○	○

Taxa	EG	WG	AI	BS	SM
Suborder Stolonifera (Stoloniferans)	●	●	●	●	●
Clavularia armata	○	○	○	○	●
Clavularia moresbii	●	●	●	○	○
Clavularia rigida	○	○	○	○	●
Clavularia sp. A	○	○	●	○	○
Sarcodictyon incrustans	●	○	●	●	○
Sarcodictyon sp. A	○	○	○	○	●
Order Gorgonacea (Gorgonians)	●	●	●	●	●
Acanella sp.	○	○	○	○	●
cf. *Acanthogorgia*	○	○	●	○	○
Alaskagorgia aleutiana	○	○	●	○	○
Amphilaphis sp. A	○	○	●	○	○
Amphilaphis sp. B	○	○	●	○	○
Amphilaphis sp. C	○	○	●	○	○
Arthrogorgia ijimai	○	○	○	○	●
Arthrogorgia kinoshitai	●	●	●	●	○
Arthrogorgia otsukai	○	○	●	●	○
Arthrogorgia utinomii	○	○	●	○	○
Calcigorgia beringi	●	○	●	○	○
Calcigorgia spiculifera	●	●	●	○	○
Calcigorgia sp. A	○	○	●	○	○
Calyptrophora japonica	○	○	○	○	●
cf. *Chrysogorgia*	○	○	●	○	●
Chrysogorgia sp. A	○	○	○	○	●
Corallium sp.	○	○	○	○	●
Cryogorgia koolsae	○	○	●	○	○
Fanellia compressa	○	○	●	●	○
Fanellia fraseri	○	●	●	○	○
Isidella elongata	○	○	○	○	●
Isidella paucispinosa	●	●	●	○	○
Isidella sp. A	○	○	●	○	●
Keratoisis profunda	●	●	●	○	○
Keratoisis sp. A	○	○	○	○	●
Keratoisis sp. B	○	○	○	○	●
Lepidisis sp. A	●	●	○	○	○
Lepidisis sp. B	○	○	○	○	●
Muriceides cylindrica	○	○	●	○	○
Muriceides cf. *cylindrica*	○	○	●	○	○
Muriceides nigra	○	○	●	○	○
Muriceides sp. A	○	○	●	○	○
Narella sp. A	○	○	●	○	○
Narella sp. B	○	○	○	○	●
Narella sp. C	○	○	○	○	●
Narella sp. D	○	○	○	○	●
Narella sp. E	○	○	○	○	●

Taxa	EG	WG	AI	BS	SM
Narella sp. F	○	○	○	○	●
Paragorgia arborea	●	●	●	●	○
Paragorgia pacifica	●	○	○	○	○
Paragorgia sp. A	○	○	○	○	●
Paramuricea sp.	○	○	●	○	○
Parastenella sp. A	○	○	●	○	●
Parastenella sp. B	○	○	○	○	●
Plumarella flabellata	○	○	●	○	○
Plumarella longispina	●	●	●	●	○
Plumarella spicata	○	○	●	○	○
Plumarella spinosa	○	○	●	○	○
Plumarella sp. A	○	○	●	○	○
Primnoa pacifica	●	●	●	●	○
Primnoa pacifica var. *willeyi*	●	●	●	○	●
Primnoa wingi	○	○	●	○	○
"*Pseudisidella*" sp.	○	○	●	○	●
Radicipes verrilli	○	○	●	○	●
Swiftia beringi	○	○	●	○	○
"cf. *Swiftia*" *marki*	●	●	●	○	○
Swiftia pacifica	●	●	●	○	●
Swiftia simplex	○	○	●	○	●
"cf. *Swiftia*" sp. A	○	●	●	○	○
Thouarella hilgendorfi	○	○	●	○	○
Thouarella striata	○	○	●	○	○
Thouarella superba	○	○	●	○	○
Thouarella sp. A	○	○	●	○	○
Order Pennatulacea (Sea Pens)	●	●	●	●	●
Anthoptilum grandiflorum	○	○	●	●	○
Anthoptilum murrayi	○	○	●	●	○
Cavernularia vansyoci	○	○	●	○	○
Halipteris californica	●	○	○	○	○
Halipteris willemoesi	●	●	●	●	○
Pennatula phosphorea	●	○	○	○	○
Protoptilum sp.	●	●	○	○	○
Ptilosarcus gurneyi	●	●	●	○	○
Umbellula lindahli	●	●	●	●	○
Virgularia sp.	●	○	○	○	○
Class Hydrozoa, Order Anthoathecatae (Stylasterids)	●	●	●	●	○
Crypthelia trophostega	○	○	●	●	○
Cyclohelia lamellata	○	○	●	●	○
Cyclohelia sp. A	○	○	●	○	○
Distichopora borealis	●	○	●	○	○
Distichopora sp. A	○	○	●	○	○
Errinopora nanneca	○	○	●	○	○

Taxa	EG	WG	AI	BS	SM
Errinopora poutalesii	●	●	●	○	○
Errinopora stylifera	○	○	●	○	○
Errinopora zarhyncha	○	○	●	○	○
Errinopora sp. A	○	○	●	○	○
cf. *Stenohelia*	○	○	●	○	○
Stylantheca papillosa	○	○	●	○	○
Stylantheca porphyra	●	○	○	○	○
Stylantheca petrograpta	●	○	●	○	○
Stylaster alaskanus	○	○	●	○	○
Stylaster brochi	○	○	●	○	○
Stylaster campylecus campylecus	●	●	●	○	○
Stylaster campylecus parageus	●	○	○	○	○
Stylaster campylecus trachystomus	○	○	●	○	○
Stylaster campylecus tylotus	○	○	●	○	○
Stylaster cancellatus	●	○	●	○	○
Stylaster elassotomus	○	○	●	○	○
Stylaster moseleyanus	○	○	●	○	○
Stylaster polyorchis	○	○	●	○	○
Stylaster stejnegeri	○	○	●	●	○
Stylaster venustus	●	○	○	○	○
Stylaster verrillii	●	○	●	○	○
Stylaster sp. A	○	○	●	○	○

STATE OF DEEP CORAL ECOSYSTEMS OF THE U.S. PACIFIC COAST: CALIFORNIA TO WASHINGTON

Curt E. Whitmire and M. Elizabeth Clarke

I. INTRODUCTION

The U.S. Pacific coast marine region encompasses the continental margin off the states of California, Oregon and Washington. Deep corals were first reported here in the 1860s with descriptions by A.E. Verrill, including two stony corals, *Balanophyllia elegans* (1864) and *Paracyathus stearnsii* (1869), and one stylasterid, *Allopora californica* (1866). Because all three of the species occur in shallow waters, it is not surprising that they were the first in the region to be reported (Cairns 1994; Ostarello, 1973). Dall (1884) also provided early descriptions of hydrocorals off California and Alaska as well as accounts from fishermen of bycatch of *Stylaster* sp. off the Farallone Islands, California as early as 1873.

In addition to the taxonomic literature, records of deep corals in the region come from a variety of other sources including catch records from regional bottom trawl surveys, bycatch data collected by fishery observers and observations from underwater vehicles (e.g., submersibles and remotely operated vehicles (ROVs)). In the early 1970s, the Alaska Fisheries Science Center (AFSC) began conducting triennial bottom trawl surveys of demersal fishes in the region. Early surveys included records of pennatulaceans and a few gorgonians. Unfortunately, identifications down to any appreciable taxonomic level were initially very limited, typically only to order or sometimes family. In 1998, the Northwest Fisheries Science Center (NWFSC) began conducting annual bottom trawl surveys, but like the early AFSC surveys, identifications of corals were initially not a priority.

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Beginning in the 1960s and continuing into the current period, there has been an increasing use of drop camera systems, submersibles and, most recently, ROVs to make *in situ* observations. These underwater photographic platforms have been used to explore numerous seafloor features in the region including rocky banks (e.g., Pearcy et al 1989; Stein et al. 1992; Pirtle 2005; Tissot et al. 2006), canyons (e.g., Yoklavich et al. 2000), escarpments (e.g., Carey et al. 1990; Clague et al. 2001), seamounts (e.g., DeVogelaere 2005) and other rocky features (Hyland et al. 2004; Brancato et al. 2007). Many of these features are known to support deep coral communities.

The disparate data sources that will be referenced throughout this report have their strengths and weaknesses as they inform discussions of deep coral communities and their habitats. For example, trawl surveys in the region are limited to low relief, sedimentary habitats that support relatively few emergent epifauna as compared with hard-bottom habitats (Figure 3.1). Consequently, bottom trawls rarely sample stony corals and stylasterids, but have resulted in numerous records of pennatulaceans as well as fewer records of gorgonians, black corals and soft corals (Table 3.1). Furthermore, the level of identification during trawl surveys varied according to the priority given for sampling of invertebrates and the level of expertise of the biologists onboard. Despite these limitations, trawl surveys encompassed large portions of the continental margin (including shelf and slope depths). Consequently, they contribute to discussions of general zoogeography of some higher coral taxa (e.g., order and family levels). On the other hand, *in situ* photographic surveys in the region primarily target rocky, high relief structures that support diverse benthic communities, many of which include corals. Surveys of this type, while limited in extent, provide detailed information about the size, health and habitat affinities of corals, and their relationships between other invertebrates and demersal fishes. One limitation of photographic surveys is the challenge of making species-level identifications, however some platforms (e.g., submersibles, ROVs) provide specimen collection capabilities.

Records of deep corals off the U.S. Pacific coast span latitudes between 32 and 49°N and from the shoreline out to the seaward boundary of the exclusive economic zone (EEZ), including depth zones from the intertidal down to the bathyal (3900 meters). In total, 101 species of corals from six cnidarian orders have been identified within the EEZ including 18 species of stony corals (Class Anthozoa, Order Scleractinia) from seven families, seven species of black corals (Order Antipatharia) from three families, 36 species of gorgonians (Order Gorgonacea) from 10 families, eight species of true soft corals (Order Alcyonacea) from three families, 27 species of pennatulaceans (Order Pennatulacea) from eleven families, and five species of stylasterid corals (Class Hydrozoa, Order Anthoathecatae, Family Stylasteridae; Appendix 3.1).

This chapter includes discussion of deep corals in the region and their communities. Brief descriptions of regional geology and oceanography set the stage for discussions of coral zoogeography and general habitat characteristics. The authors attempted to identify all taxa known to occur in the region, and taxa that provide vertical structure as potential habitat for other organisms are highlighted. In addition, the chapter includes a review of potential impacts to corals in the region and related conservation measures enacted to protect coral communities

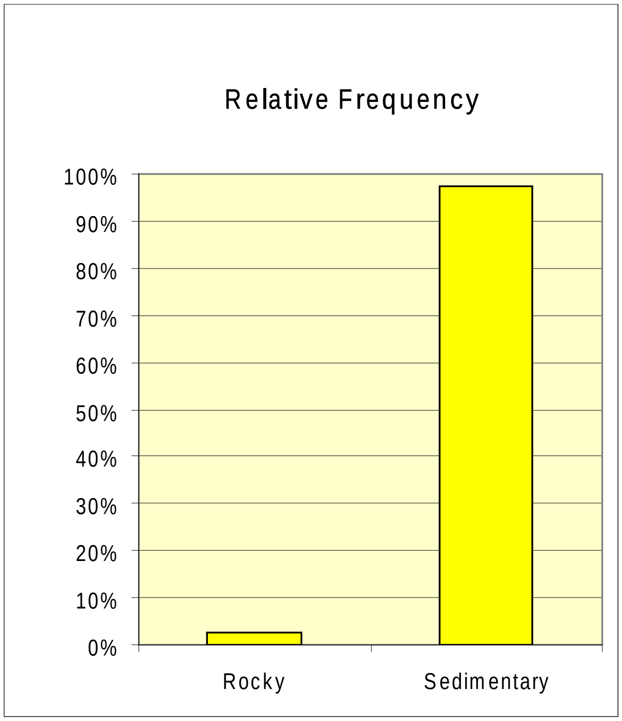

Figure 3.1. Distribution of general seafloor lithologies transected by bottom trawls conducted by the Northwest Fisheries Science Center (NWFSC) from 2001-2003 during surveys of groundfish off the coast of Washington, Oregon and California. Only trawls where the position of the fishing gear was known were used for analysis. Lithology information for the continental margin off Washington and Oregon was provided by the Active Tectonics and Seafloor Mapping Lab at Oregon State University. Lithology information for off California was provided by the Center for Habitat Studies at Moss Landing Marine Laboratories.

Table 3.1. General statistics on deep corals sampled during National Marine Fisheries Service (NMFS) bottom trawl surveys, which were conducted off the coasts of Washington, Oregon and California by the Alaska and Northwest Fisheries Science Centers between 1980 and 2005. A total of 10,526 trawl catch records were queried.

	# Trawls with Corals	% Trawls with Corals	% Coral Records
Pennatulaceans	1683	16.0%	74.5%
Gorgonians	202	1.9%	8.9%
Antipatharians	197	1.9%	8.7%
Alcyonaceans	150	1.4%	6.6%
Scleractinians	26	0.2%	1.2%
Stylasterids	1	<0.1%	<0.1%
Total	2259		100.0%

and their habitats. Finally, the authors provide recommendations for future research to improve our understanding of these organisms.

II. GEOLOGICAL SETTING

The marine region off the coasts of Washington, Oregon and California accounts for about 7% (778,628 km^2) of the total area of the U.S. EEZ (NMFS 2007 in prep). The continental margin in this region is characterized by a narrow (5-40 km) shelf and steep continental slope, with the shelf break at approximately 200 meters water depth. The outer continental shelf off Oregon and parts of California are marked by large rocky banks (Figure 3.2), some of which were at or near the surface during the lower sea level stands of the glacial epochs. Several of these banks as well as other bathymetric features such as pinnacles and seamounts create localized upwelling conditions that concentrate nutrients, thus driving a high level of biologic productivity. For example, Heceta Bank, which rises over 100 meters above the edge of the continental shelf and to within 70 meters of the ocean surface, diverts the main flow of the California Current, introducing eddies and other instabilities that affect areas downstream and along the Oregon coast. Smaller rocky banks are located off southern California in what is called the continental borderlands, a geologically complex region characterized by deep basins and elevated ridges, some of which breech the surface to form the Channel Islands. Throughout the region, many of these high relief, bathymetric features have been found to support coral communities (see Love et al. 2007; Tissot et al. 2006; Tissot et al. in prep; Strom 2006).

The shelf and slope are cut by numerous submarine canyons, including one of the deepest and largest on the west coast of North America - Monterey Canyon (Figure 3.2). Deep corals have been discovered at numerous sites here, and also within another large canyon – Astoria – located directly off the mouth of the Columbia River. Other major canyons include Juan de Fuca, Quinault, Bodega, Pioneer and Sur Canyons.

Beyond the slope, a number of seamounts rise above the abyssal plain including Thompson, President Jackson, San Juan, Rodriquez, Taney, Guide, Pioneer and Davidson (Figure 3.2). The seamounts off the west coast of North America have formed over the past tens of millions of years by hotspot volcanism and by enhanced melting in association with the migration of the spreading centers over a heterogeneous mantle (Davis and Karsten 1986). One of the largest seamounts – Davidson – has been the site of several ROV surveys that have discovered a diverse coral community (see DeVogelaere 2005). A number of additional seamounts that are known to support deep corals lie just to the west of the EEZ boundary, including Cobb, Brown Bear, Fieberling and Jasper.

Other megascale (i.e., km to 10s of km, Greene et al. 1999) structural features in the region that contribute hard-bottom habitats include the Mendocino and Gorda Ridges (Figure 3.2). The Mendocino Fracture Zone is a 3000-km long transform fault extending from Cape Mendocino, California across the Pacific Plate. A prominent hard-bottom feature associated with this fault is the Mendocino Ridge, which shoals to 1100 meters water depth and drops 2100 meters to the north-south trending Gorda Ridge. To the south, the Mendocino ridge slopes 3300 meters to the abyssal plain. In contrast to the Mendocino Ridge, the Gorda Ridge is a seafloor spreading center where two plates are moving apart, allowing molten magma to rise up to form new oceanic crust. It extends 300 km and is bounded by the Mendocino Fracture Zone to the south and the Blanco Fracture Zone to the north. The Gorda Ridge rises to a maximum height of >1500 meters above the axial valley floor, which ranges from 3200 to >3800 meters water depth. Like other spreading centers, hydrothermal vents that support unique communities of chemosynthetic organisms exist nearby. Morphology of the Mendocino and Gorda Ridges were described by Fisk et al. (1993) and Clague and Holmes (1987), respectively.

III. OCEANOGRAPHIC SETTING

Oceanographic circulation in the region is well described and was summarized recently by NMFS (2007 in prep). The U.S. Pacific region is one of the major upwelling areas of the world, where nutrient-rich waters support high levels of biological productivity. Physical oceanography varies seasonally and during El Niño and La Nina events or periods of interdecadal climate regime shifts. Major oceanographic currents

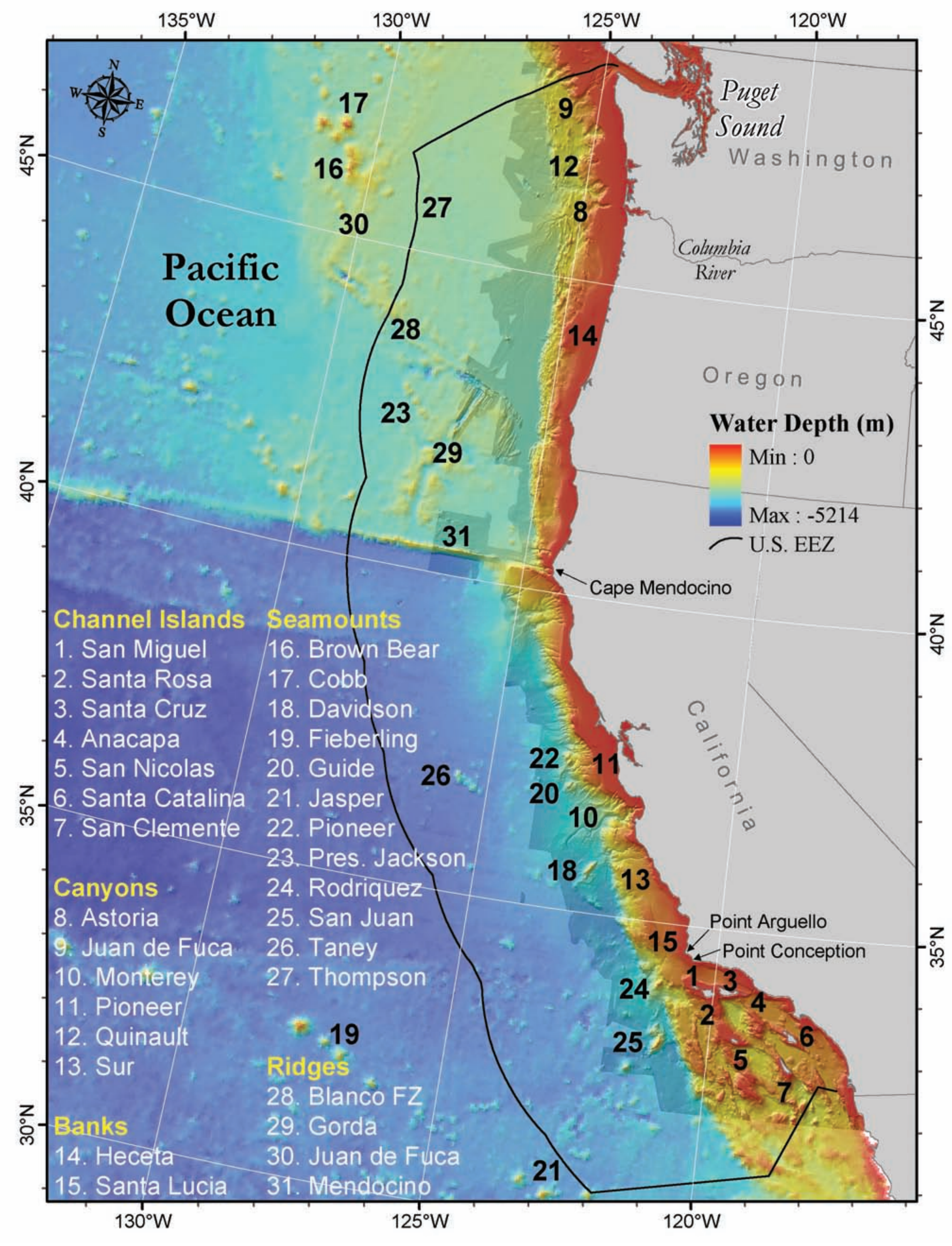

Figure 3.2. Bathymetric map of the U.S. Pacific coast region. Major topographic features that are mentioned in this chapter are labeled.

in the region include the surface-flowing California Current, the Inshore Countercurrent (Davidson Current) and the Southern California Countercurrent, and the subsurface-flowing California Undercurrent. The California Current forms the eastern boundary of a large clockwise circulation pattern in the North Pacific. The California Current is a year-round flow that transports cold, nutrient-rich subarctic water equatorward (Hickey 1998). It extends from the shelf break to about 1000 km offshore with peak speeds at the surface during spring and summer yet significant flows down to 500 meters (Hickey 1998). South of Point Conception, the California Current splits, with its core continuing farther offshore while a smaller portion turns shoreward both north and south of the Channel Islands (Figure 3.3). Near San Diego, part of the core flow turns northward to form the Southern California Countercurrent, an inshore poleward flow off Southern California. During some years, the Southern California Countercurrent forms a counterclockwise circulation pattern known as the Southern California Eddy (Figure 3.3). During other years, the Southern California Countercurrent rounds Point Conception and combines with the Inshore Countercurrent, a poleward flow inshore of the equatorward California Current (Hickey 1979, Figure 3.3). Below these surface currents lies a narrow, high speed flow known as the California Undercurrent, which brings warmer, nutrient-poor waters poleward along the slope from the eastern equatorial Pacific (Pierce et al. 2000). A major feature of the eastern North Pacific and the California Current is a layer where oxygen concentrations are low within a depth zone along the upper continental slope, extending to depths greater than 1000 m. This feature lies beneath the California Undercurrent and is called the oxygen minimum zone (dissolved oxygen <0.5 ml l^{-1} (22 mM kg^{-1}) (Deuser 1975).

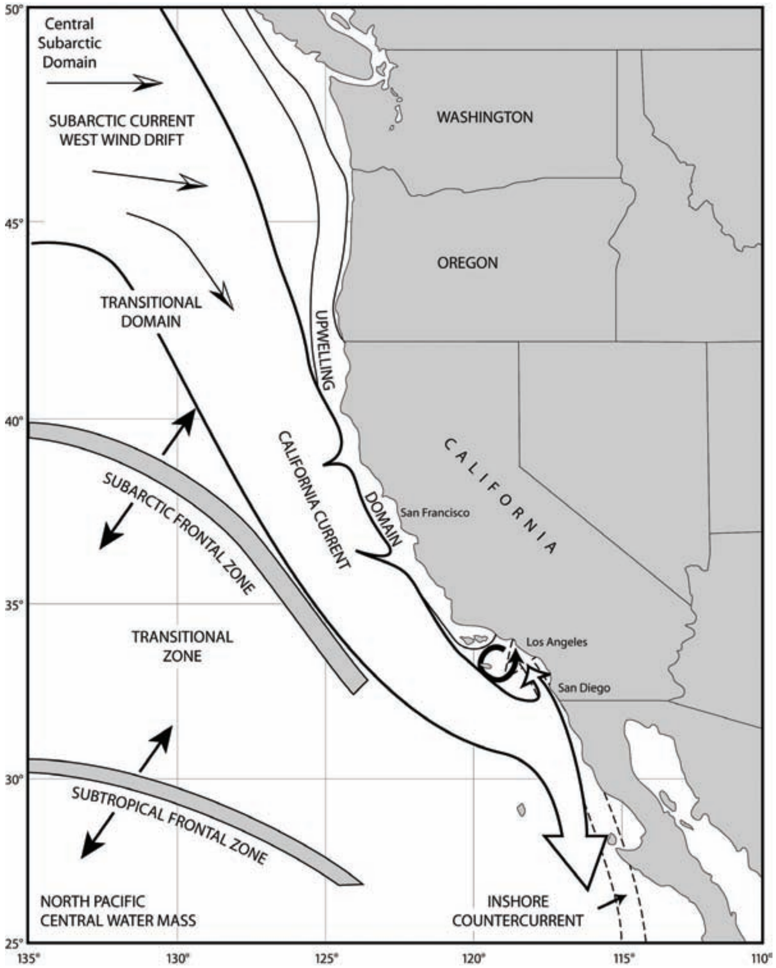

Figure 3.3. Map of portion of the Pacific coast of North America showing major oceanographic currents. Image source: NMFS 2007, in prep.

Circulation in the region is driven by the intensity and duration of prevailing seasonal winds and storms. Spring and summer northwesterly winds drive an upwelling system that replenishes nutrients to the photic zone, which in turn stimulate biological productivity (Batchelder et al. 2002). A shift in wind direction in the winter north of Santa Cruz, CA creates favorable downwelling conditions, while upwelling conditions persist year-round south of Santa Cruz due to modest storm activity (Strub and James 2000). Upwelling plumes also occur at coastal headlands, particularly where the California Current and Inshore Countercurrent intersect off Pt. Conception.

Another important hydrographic feature in the northern part of the region is the Columbia River plume, contributing as much as 90% of the freshwater input between the Strait of Juan de Fuca and San Francisco Bay (NMFS 2007 in prep). The position of the plume is highly seasonal, generally extending equatorward and offshore in the spring and summer, and poleward along the coast in the fall and winter (Thomas and Weatherbee 2006).

According to Briggs (1974), the temperate northeastern Pacific includes three coastal zoogeographic provinces, two of which include waters off Washington, Oregon and California. The San Diego Province, in the warm-temperate region, extends from Point Conception, CA south to Magdalena Bay, Baja California Sur, Mexico. The Oregon Province is the lower boreal province in the cold temperate region and extends from Point Conception north to the Dixon Entrance, the maritime boundary between Alaska and British Columbia. Another review of Pacific Ocean zoogeography by McGowan (1971) placed the northern boundary of the Oregon (or "Oregonian") Province at the Strait of Juan de Fuca.

IV. STRUCTURE AND HABITAT-FORMING DEEP CORALS

Several coral taxa in the region are designated as "structure-forming", meaning they are known to provide vertical structure above the sea floor that can be utilized by other invertebrates or fish. Attributes contributing to structure include morphology (i.e., branching vs. non-branching), whether or not the taxa is known to form reefs, relative abundance, maximum colony size, manner of colony spatial dispersion (i.e., solitary vs. clumped) and the relative number of associations with other organisms (Table 3.2). With the exception of maximum colony size, structure-forming attributes are specific to records of corals in the region. Likewise, discussions of structure-forming taxa that follow are limited to current information in this region. Taxa that are considered structure-forming in other regions may not be designated as so in this region due to lack of specific information on structural attributes.

a. Stony corals (Class Anthozoa, Order Scleractinia)

Stony corals off the Pacific coast include 18 species from seven families (Appendix 3.1). Most of the records of stony coral are of solitary, non-branching cup corals (e.g., *Balanophyllia elegans*). However, at least seven branching species are known to occur in the region, including *Lophelia pertusa*, *Oculina profunda*, *Madrepora oculata*, *Dendrophyllia oldroydae*, *Astrangia haimei*, *Labyrinthocyathus quaylei* and *Coenocyathus bowersi*. *L. pertusa* is widely distributed off southern California (Hardin et al. 1994; Mary Elaine Helix, MMS, pers. comm.) and has been collected at four sites in the Olympic Coast National Marine Sanctuary (Hyland et al. 2004; Brancato et al. 2007). One site in the Olympic Coast NMS may support the largest aggregation of *L. pertusa* reported in the northeast Pacific. Because of this discovery and the fact that *L. pertusa* is relatively abundant off southern California, it was given a high rating of structural importance (Table 3.2). Other structure-forming stony corals are *Dendrophyllia oldroydae* and *Oculina profunda* (Stephen Cairns, Smithsonian Institution, pers. comm.; Table 3.2).

b. Black corals (Class Anthozoa, Order Antipatharia)

Antipatharians are very abundant off the Pacific coast but not very speciose with only seven species from three families, Antipathidae, Cladopathidae and Schizopathidae (Opresko 2005, 2003, 2002, Appendix 3.1). *Antipathes* sp. and *Bathypathes* sp. exhibit coast wide distributions, while *Lillipathes* sp. and *Umbellapathes* sp. have only been collected at Davidson Seamount (Erica Burton, Monterey Bay NMS, pers. comm.). *Antipathes* sp. and *Bathypathes* sp. are branching, can reach heights >30 cm, and occur in high abundance. *A. dendrochristos* (Opresko 2005), a newly described species ranging in height from 10 to 250 cm, has been observed via submersible on several deepwater banks off southern California at water depths between 90 and 360 meters (Love et al. 2007; Tissot et al. 2006; Yoklavich and Love 2005). Many of these specimens showed epifaunal associations with other invertebrates including crinoids, amphipods, brittle stars, anemones, sponges and crabs. One large (2.1 m high) dead colony, which was heavily colonized by over 2500 invertebrate individuals, was recently aged to 140 years (Love et al. 2007). For these reasons, *Antipathes* spp. was given a high rating of structural importance (Table 3.2).

c. Gold corals (Class Anthozoa, Order Zoanthidea)

Gold corals are very rare in the region, with only one unconfirmed record from Davidson Seamount (DeVogelaere et al. 2005).

d. Gorgonians (Class Anthozoa, Order Gorgonacea)

Gorgonians are the most speciose group of corals off the Pacific coast with 36 species from 10 families (Appendix 3.1). *Paragorgia arborea* is found in high abundance (including extensive

Table 3.2. Structure-forming attributes of some deep coral taxa off the U.S. Pacific coast. Relative abundance data was compiled from taxonomic records, *in situ* photographic surveys, and to a lesser extent bottom trawl surveys. Numbers of species associations were quantified from *in situ* photographic surveys. Size, morphology and other colony attributes were informed by taxonomic descriptions. '?' means insufficient data available in the region to comment.

	Attributes Contributing To Structure						
Taxa	**Reef-Building**	**Relative Abundance**	**Maximum Colony Size**	**Morphology**	**Associations with Other Species**	**Colony Spatial Dispersion**	**Overall Rating of Structural Importance**
Lophelia pertusa	No	High	Large	Branching	Many	Clumped	High
Oculina profunda	No	Low	?	Branching	?	?	Low
Dendrophyllia oldroydae	No	Medium	Medium	Branching	?	Clumped	Medium
Antipathes dendrochristos	No	High	Large	Branching	Many	Solitary	High
Bathypathes sp.	No	High	Medium	Branching	?	Solitary	Medium
Isidella sp.	No	High	Medium	Branching	?	Solitary	Medium
Keratoisis sp.	No	High	Medium	Branching	?	Solitary	Medium
Paragorgia arborea	No	High	Large	Branching	Many	Solitary	High
Primnoa pacifica	No	Low	Large	Branching	Many	Solitary	High

Table Key	
Attribute	Measure
Reef-Building	Yes/No
Relative Abundance	Low/ Medium/ High
Size (width or height)	Small (< 30cm)/ Medium (30cm-1m)/ Large (>1m)
Morphology	Branching/ Non-branching
Associations	None/ Few (1-2)/ Many (>2)
Spatial Dispersion	Solitary/ Clumped
Overall Rating	Low/ Medium/ High

"forests" observed along several ridges on Davidson Seamount [DeVogelaere et al. 2005]), can reach heights >1 m and has shown epifaunal relationships with numerous other structure-forming invertebrates. *P. arborea* is therefore given a high rating of structural importance (Table 3.2). *Isidella* spp. and *Keratoisis* spp. are found coast wide mostly on the continental slope. Although both genera can reach heights greater than 30 cm, other gorgonians (e.g., *P. arborea* and *Primnoa pacifica*) in the region can reach heights exceeding 1 meter. Therefore, *Isidella* and *Keratoisis* were given a medium rating of structural importance (Table 3.2). ROV surveys in the Olympic Coast NMS have resulted in numerous observations of gorgonians including large colonies of *P. pacifica*, numerous colonies of *Plumarella longispina* and smaller colonies of *Leptogorgia chilensis, Swiftia pacifica,* and *Swiftia beringi* at several sites. Colonies of *P. pacifica* obtained off La Jolla, CA (north of San Diego) at 205-234 meters are the southernmost record of the species in the Pacific (Cairns and Barnard 2005). Specimens of *Keratoisis* and *Corallium* from Davidson Seamount have been aged to over 200 and 115 years, respectively (Andrews et al. 2005).

e. *True soft corals* (Class Anthozoa, Order Alcyonacea)

Only eight species of true soft corals from three families occur off the Pacific coast (Appendix 3.1). *Anthomastus* sp. is abundant and exhibits coast wide distributions, while *Gersemia* sp. has been caught primarily on the northern Oregon slope during trawl surveys. *Alcyonium rudyi* and *Cryptophyton goddarti* were described recently (1992 and 2000, respectively) off the Oregon coast (Cairns et al. 2002). Other than *C. goddarti*, references to *Clavularia* and *Telesto* off southern California (SCAMIT 2001), and *Telestula ambigua* in deep water off central California (Austin 1985), there are no other data on stoloniferans in the region. Because of their small stature, none of the true soft corals in the region are considered to be structure-forming.

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

Pennatulaceans are the most abundant coral taxon in the region and have been observed from submersibles and ROVs either alone or in groves of numerous individuals similar to aggregations observed off Alaska (Stone et al. 2005; Brodeur 2001). They are also the most common coral taxon recorded from trawl surveys (Table 3.1). To date, 27 species from eleven families are known to occur off the Pacific coast (Appendix 3.1). *Stylatula* sp., *Anthoptilum grandiflorum* and *Umbellula* sp. are the most common taxa, all of which are found coast wide. Although groves of pennatulaceans have been shown to support higher densities of some fish species than adjacent areas (e.g., Brodeur 2001), they are not considered to be structure forming as defined by this report.

g. *Stylasterid corals* (Class Hydrozoa, Order Anthoathecatae, Suborder Filifera)

Lace corals or stylasterid corals off the Pacific coast have been observed colonizing moderate to high-relief rocky habitats from the intertidal down to shelf water depths. Only five species from three genera are known to occur in the region (Fisher 1938; Cairns 1983; Alberto Lindner, pers. comm., Appendix 3.1). *Stylaster californicus* is the only species known from the San Diego Province while *S. venustus* is found throughout the Oregon Province. Other species that exhibit narrower distributions in the Oregon Province include *Errinopora pourtalesii*, *Stylantheca porphyra* and *S. petrograpta* (Fisher 1938; Cairns 1983). The two *Stylaster* species and *E. pourtalesii* are flabellate (i.e., fan-shaped) while *Stylantheca* is encrusting (Cairns 1983). Because most specimens in the region rarely exceed 30 cm in height or width, they are not considered to be structure-forming. Stylasterid corals have rarely been identified in trawl survey catches (Table 3.1), most likely because bottom trawls do not target the high-relief habitats and shallow depths at which stylasterids are typically found.

V. SPATIAL DISTRIBUTION OF CORAL SPECIES AND HABITATS

Much of the information on general zoogeography of corals in the region originates from taxonomic records and bottom trawl surveys conducted by the National Marine Fisheries Service (NMFS) (Appendix 3.1). The Alaska Fisheries Science Center (AFSC) conducted regional trawl surveys off the Pacific coast from 1971-2001, and the Northwest Fisheries Science Center (NWFSC) began ongoing surveys in 1998. Identification of invertebrates was initially very limited; therefore this report focuses on catch records from 1980-2005. Cumulatively, both surveys covered much of the continental shelf and upper slope (10-1600 m water depth); however, survey effort has been spatially and temporally variable. Prior to 2002, there was limited trawl survey effort south of Pt. Conception (34.5ºN). Also, the number of trawls conducted during each survey varied from year to year. A total of 7252 AFSC and 3274 NWFSC trawl catch records were queried for coral occurrences. Pennatulaceans were recorded in 16% of survey trawls, while all other coral taxa occurred in only 5% of trawls (Table 3.1, Figure 3.4). In addition to NMFS, the Southern California Coastal Water Resource Project (SCCWRP) conducted bottom trawls during three different continental shelf surveys off southern California from 1994 to 2003 (Allen et al. 1998; Allen et al. 2002). Catch records from 304 of 957 (32%) SCCWRP trawls include 316 records of pennatulaceans encompassing thirteen species from six families, and 225 records of other corals encompassing fifteen species from six families.

In addition to trawl surveys, Etnoyer and Morgan (2003) compiled records of observations and collections of structure-forming corals off the Pacific coast by the California Academy of Sciences (CAS), the Monterey Bay Aquarium Research Institute (MBARI), the Smithsonian’s National Museum of Natural History (NMNH), and Scripps Institution of Oceanography (SIO). Taxonomists have confirmed the identities of some of these records, but many records are limited to higher taxa (e.g., genus and family). Records off Washington, Oregon and California include representatives from two families of stony corals (Oculinidae and Caryophyllidae), one family of black corals (Antipathidae), four families of gorgonians (Corallidae, Isididae, Paragorgiidae and Primnoidae) and stylasterid corals (Family

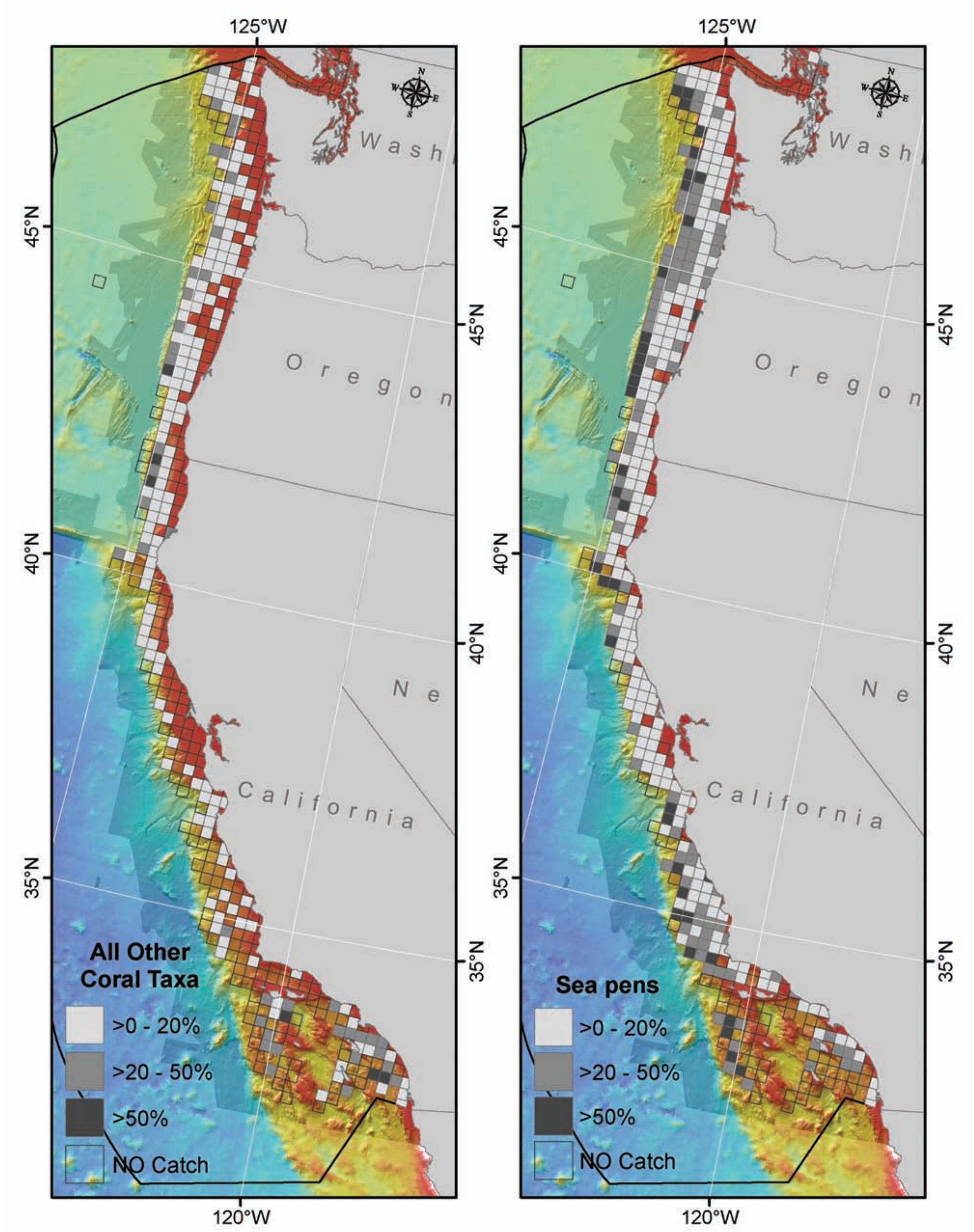

Figure 3.4. Maps of frequency of occurrence for two groups of deep coral taxa sampled during NMFS bottom trawl surveys (1980-2005). Frequency defined as number of trawls with corals identified in the catch sample divided by total number of trawls within each 20x20 km cell. Frequency was categorized into three classes: >0-20%, >20-50%, and >50%. Cells where survey trawls occurred but where no corals were identified in the catch sample are labeled as “NO Catch” and are symbolized with an empty box where the underlying bathymetry shading is visible. Pennatulaceans were singled out because they inhabit different habitat types and were caught much more frequently than other coral taxa. See Table 3.1 for frequency information.

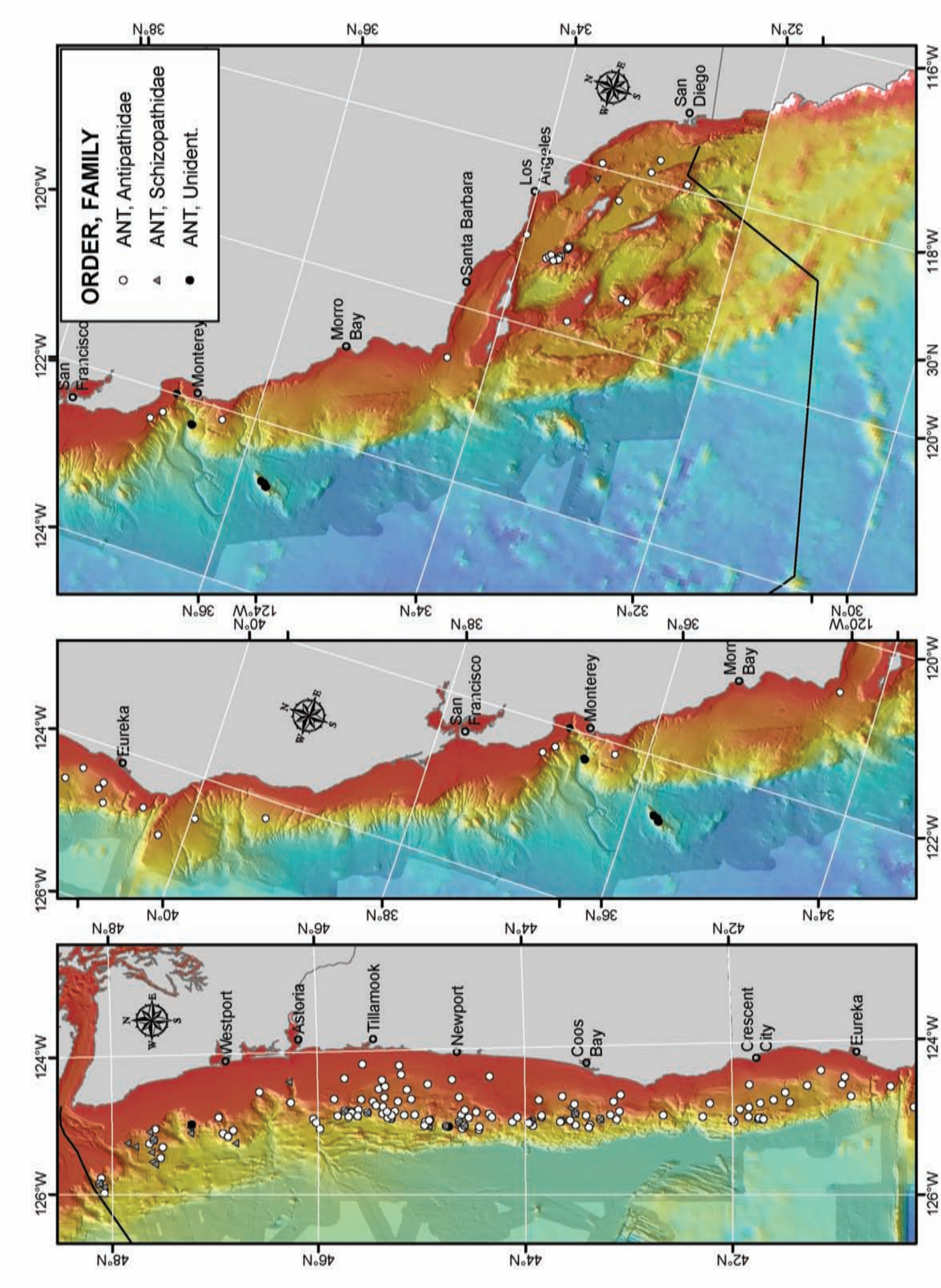

Figure 3.5. Map showing locations of black corals (Order Antipatharia) from NWFSC, AFSC, and SCCWRP trawl surveys, Etnoyer and Morgan (2003) and Tissot et al. (2006). Specific identities from trawl survey catch records are unconfirmed and primarily limited to genus or family level.

Stylasteridae). A total of 389 records of corals span much of the EEZ off the U.S. Pacific coast. This information contributes to the general zoogeography of coral taxa in the region, many of which are highlighted in the following sections pertaining to the two zoogeographic provinces.

More detailed information on coral habitats in the region is provided by *in situ* photographic surveys. When possible, the data sources and brief descriptions of these surveys are provided.

San Diego Province

The U.S. portion of the San Diego Province extends from the Mexican border, north to Point Conception, CA, and includes the geologically

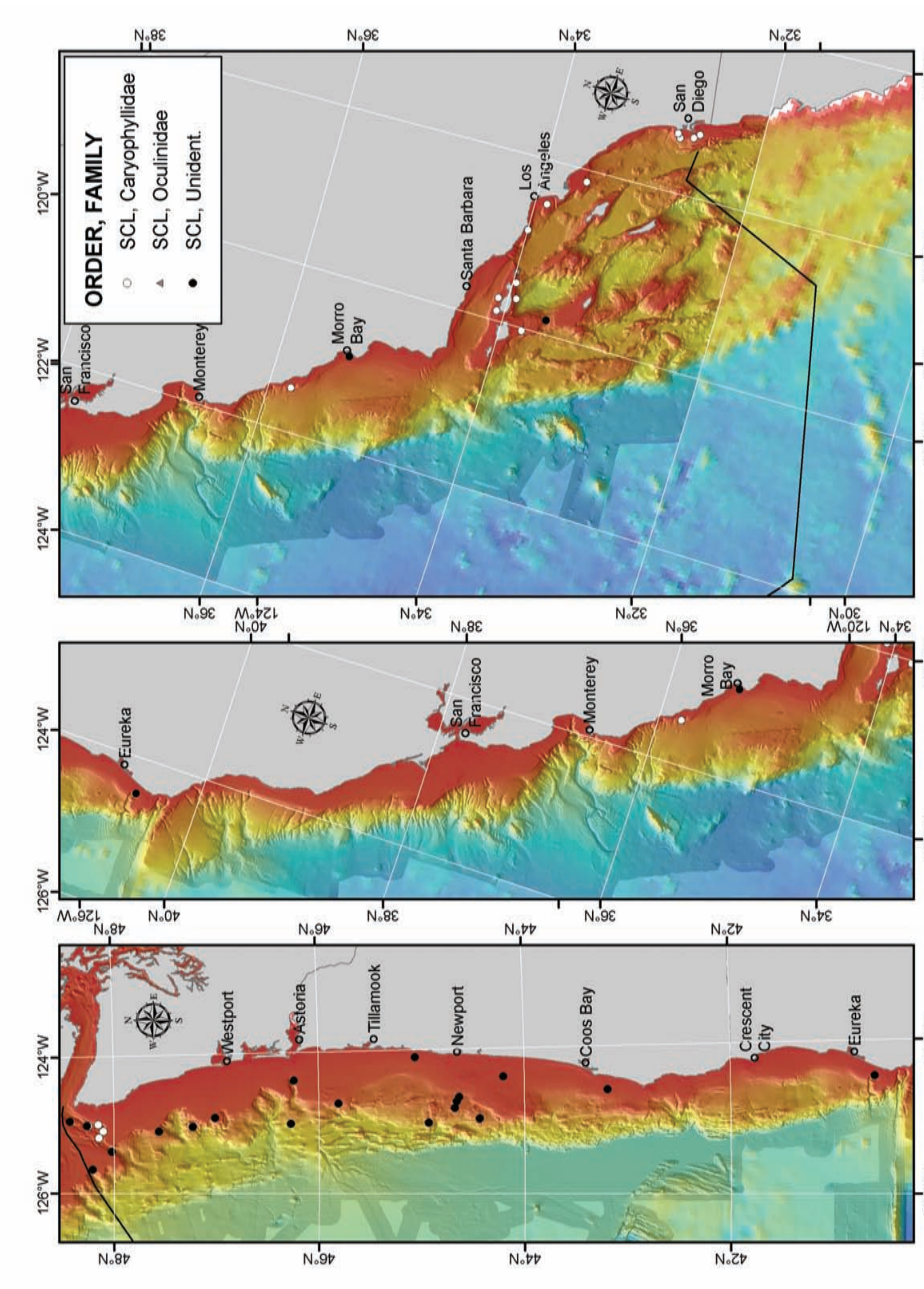

Figure 3.6. Map showing locations of stony corals (Order Scleractinia) from NWFSC, AFSC, and SCCWRP trawl surveys, Etnoyer and Morgan (2003) and Brancato et al. (in review). Specific identities from trawl survey catch records are unconfirmed and primarily limited to genus or family level.

complex borderlands (Figure 3.2). A number of species found in this region, such as the newly described black coral, *Antipathes dendrochristos* (Opresko 2005) have not been described further north. These black corals have been observed via submersible on numerous rocky outcrops in the province at water depths ranging from 90 to 360 m (Love et al. 2007; Tissot et al. 2006; Yoklavich and Love 2005, Figure 3.5). *Lophelia pertusa* and *Desmophyllum dianthus* have been observed on numerous high-relief, hard-bottom features below 120 meters near oil platforms surveyed in the late 1980s off Pt. Conception, CA (Steinhauer and Imamura 1990; Hardin et al. 1994). Near one platform, *D. dianthus* and *L. pertusa* were among the most abundant taxa observed in high-

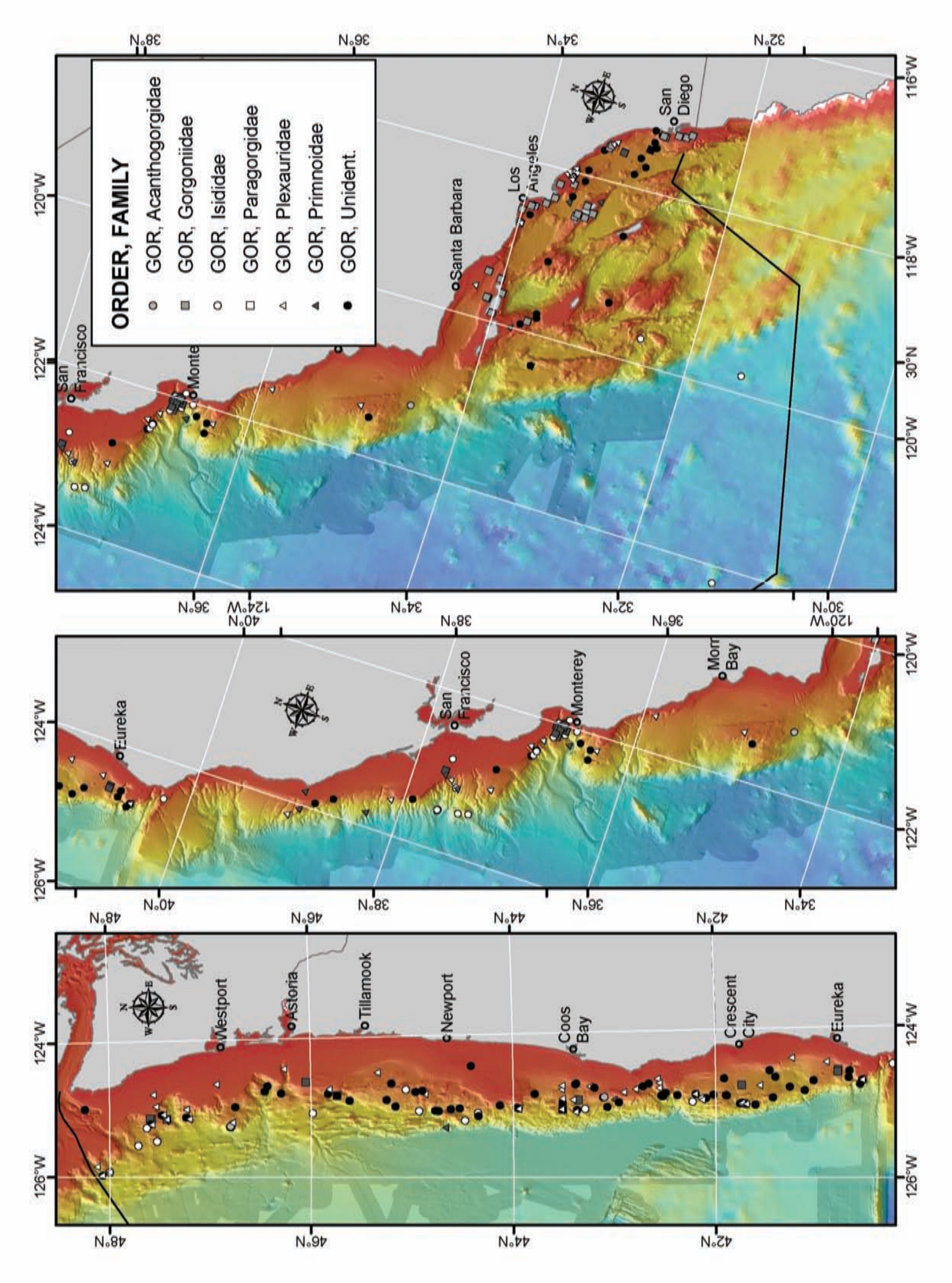

Figure 3.7. Map showing locations of gorgonians (Order Gorgonacea) from NWFSC, AFSC, and SCCWRP trawl surveys, Etnoyer and Morgan (2003) and Tissot et al. (2006). Specific identities from trawl survey catch records are unconfirmed and primarily limited to genus or family level.

relief habitats at water depths ranging from 160-212 meters. Another scleractinian, *Caryophyllia arnoldi*, is known to occur throughout the province especially around the Channel Islands (Cairns 1994). The cup coral, *Paracyathus stearnsii*, is also common around the Channel Islands including 25 specimens deposited at SIO (Cairns 1994). *Coenocyathus bowersi* has been collected from the nearshore off the coasts of mainland California, around the Channel Islands and down to 80 meters off Pt. Conception (Cairns 1994). One record of the colonial scleractinian, *Madrepora oculata,* collected at 84 meters water depth near Anacapa Island, is only one of two records known from the northeast Pacific (Cairns 1994, Figure 3.6).

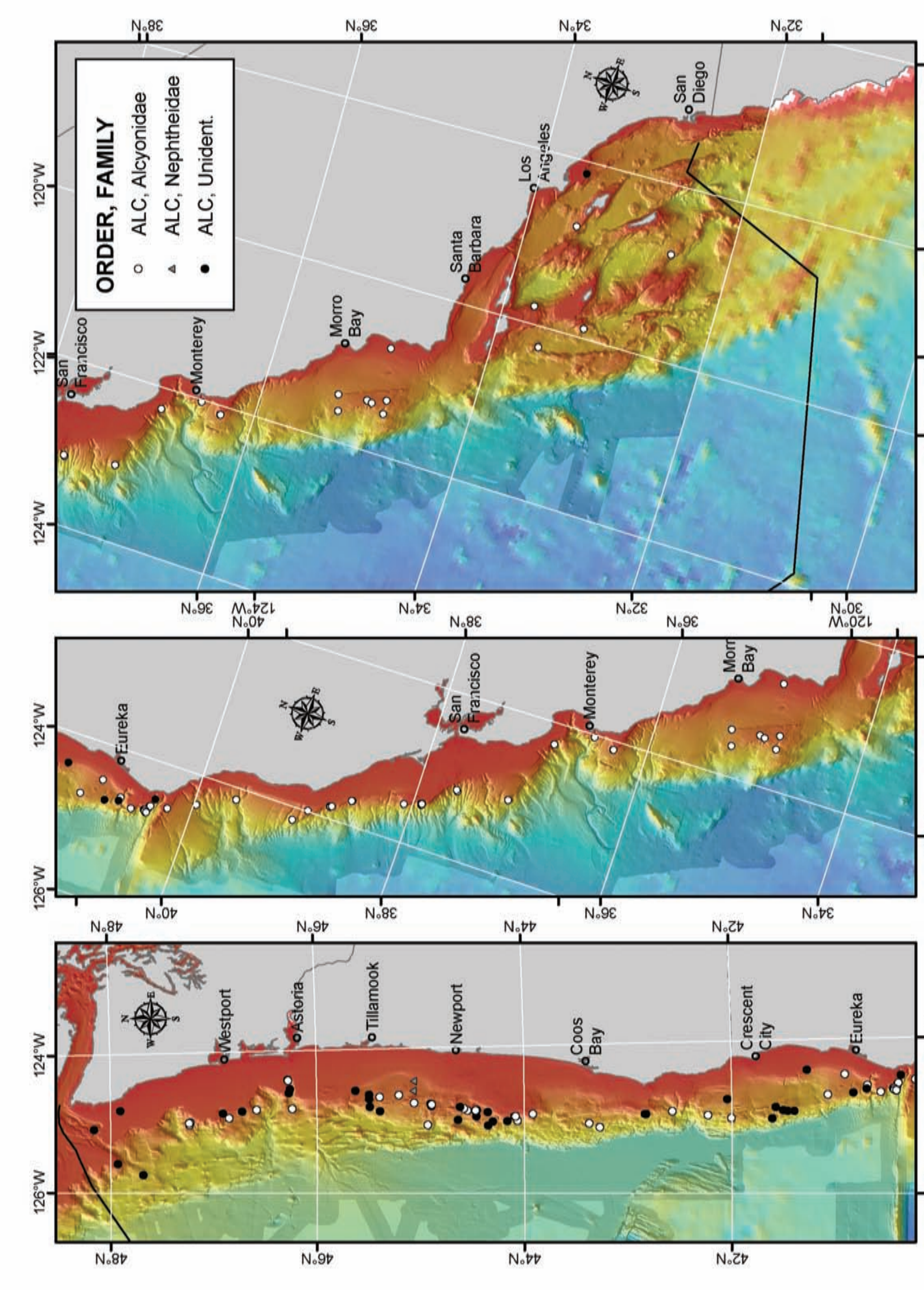

Figure 3.8. Map showing locations of true soft corals (Order Alcyonacea) from NWFSC, AFSC, and SCCWRP trawl surveys and Etnoyer and Morgan (2003). Specific identities from trawl survey catch records are unconfirmed and primarily limited to genus or family level.

Gorgonians are not as prevalent as they are in the Oregon Province (Figure 3.7); however, this may be due to sampling bias. Tissot et al. (2006) observed 27 specimens from four different habitat types at 144-163 m. Other records in the province include *Lepidisis* sp. at 950 m and *Keratoisis* sp. far offshore San Diego at 3180 and 3880 m (Etnoyer and Morgan 2003). Gorgonian catches from trawl surveys range in water depths from 77-1400 meters. Pennatulaceans (mostly members of suborder Subselliflorae) have been observed from underwater vehicles in the sedimented flanks of numerous rocky outcrops in the province (9726 specimens from Tissot et al. 2006) and are caught more often than other coral taxa in bottom trawls at water depths ranging from 44 to over 1500 meters. The only stylasterid coral known to occur in the province is *Stylaster californicus*, which has been recorded in rocky habitats down to 90 meters water depth.

Oregon Province

The Oregon Province, which extends from Pt. Conception, CA north to the maritime boundary between Alaska and British Columbia, and includes one of the more recent discoveries of structure-forming stony coral off the U.S. Pacific coast – *Lophelia pertusa* at the Olympic Coast NMS. During ROV surveys, *L. pertusa* was observed on a rock ledge in 271 meters of water in 2004 (Hyland et al. 2004) and at three other sites in 2006, including a broad (tens of meters wide), low-lying mound (<1 meter high) at approximately 250 meters water depth (Brancato et al. 2007). Both dead and living colonies were observed. *Desmophyllum* sp. was also observed in association with *L. pertusa* (Brancato et al. 2007), which is consistent with observations of *Lophelia* elsewhere in the region and world (see Hardin et al. 1994; Cairns and Stanley 1982). Colonies of the stylasterid coral, *Stylaster venustus*, were observed in water depths of about 100 meters off Cape Flattery, WA (A. Lindner, pers. obs.).

Scleractinians and stylasterids are also found elsewhere in the province. *Labyrinthocyathus quaylei* is found on Cordell Bank and south to San Diego at water depths of 37-293 m (Cairns 1994). Stylasterids and solitary cup corals are common primarily in nearshore hard bottom habitats (Cairns 1983, 1994), including over 36,000 observations of *Balanophyllia elegans* at Cordell Bank (Pirtle 2005). During surveys of proposed submarine cable routes off Pt. Arguello, CA, epifaunal coverage of *Stylantheca porphyra,* two cup corals (*B. elegans* and *Paracyathus stearnsii*) and two species of anemones often reached 100 percent on moderate-relief hard-bottom habitats (Aspen 2006). *Caryophyllia arnoldi* is known from throughout the Oregon Province including inside waters of Washington state and British Columbia. *Paracyathus stearnsii* is common in Monterey Bay including 45 specimens deposited at CAS (Cairns 1994). The Farallone Islands (off San Francisco, CA) mark the northern and southern distributional extents of two stylasterid corals, *Stylaster californicus* and *S. venustus*, respectively. Other stylasterids include *Errinopora pourtalesii*, which is found off central California at shelf depths, and *Stylantheca petrograpta*, which is found only in the northern part of the province off the southern part of Vancouver Island and in Puget Sound (Fisher 1938; Alberto Lindner, pers. comm.).

Black corals in the Oregon Province are most prevalent north of Cape Mendocino with the largest reported catches from the northern Oregon slope (Figure 3.5). *Chrysopathes speciosa* and *Antipathes* sp. are the most common antipatharian taxa in the province and entire region. Gorgonians are common at all depths covered by regional trawl surveys but also more common north of Cape Mendocino (Figure 3.6). They have also been recorded from water depths over 2900 m off San Francisco, CA (Etnoyer and Morgan 2003). During submersible dives off the Oregon coast in the mid-1990s, high densities of gorgonians were observed at depths between 200 and 250 meters, where hard rocky substrate was covered with thick, hummocky sediments at the southern edges of submerged rocky banks (Strom 2006). Despite being the second-most abundant invertebrate taxa observed (21% of all organisms encountered), gorgonians observed at these sites did not exceed 30 cm in height. The soft coral, *Anthomastus* sp., has been caught over all latitudes but only on the slope (Figure 3.8). Pennatulaceans are ubiquitously distributed throughout the region both by latitude and depth (Figure 3.9). Most specimens are *Stylatula* sp., but *Anthoptilum grandiflorum*, *Ptilosarcus gurneyi* and *Umbellula* sp. are also abundant and widely distributed. As in the San Diego Province, they prefer sedimentary habitats and *Stylatula* has been observed in dense groves.

VI. SPECIES ASSOCIATIONS WITH DEEP CORAL COMMUNITIES

Several studies both in the region and elsewhere in the north Pacific report fine-scale associations between demersal fishes, corals and other structure-forming invertebrates (e.g., Stone 2006; Krieger and Wing 2002; Brodeur 2001; Hardin et al. 1994; Hixon et al. 1991) and some studies have even investigated the nature of those relationships (e.g., Tissot et al. 2006; Auster 2005; Pirtle 2005; Parrish 2004; Syms and Jones 2001). In addition to *in situ* observations, corals have been collected with other invertebrates and fishes during bottom trawl surveys and commercial fishing operations. Unfortunately,

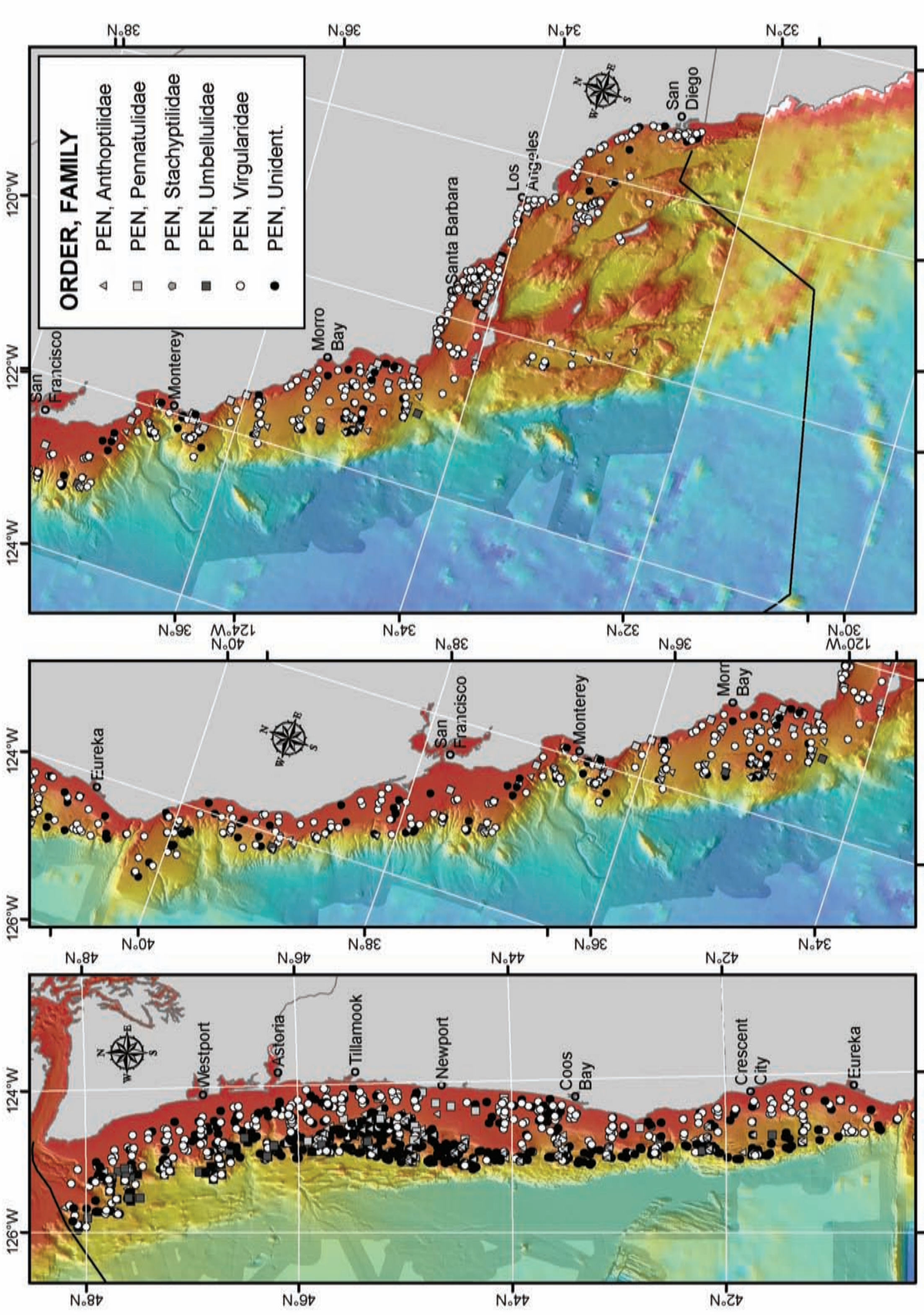

Figure 3.9. Map showing locations of pennatulaceans (Order Pennatulacea) from NWFSC, AFSC, and SCCWRP trawl surveys. Specific identities from trawl survey catch records are unconfirmed and primarily limited to genus or family level.

bottom trawls are of limited precision because they often extend over kilometers of seabed, traversing a variety of low-relief habitats. Furthermore, trawl gears are not designed to target sessile invertebrates. Therefore, catches of corals only represent presence data, and cannot be used to develop standardized indices of coral abundance. Lastly, catches of corals often consist of partial colonies or skeletal fragments, making it difficult to ascertain the size and overall health of the organism. Consequently, the best source of data on species associations comes from direct observations via submersibles or other *in situ* photographic methods (e.g., ROVs). Three studies in particular have examined the nature of relationships between deep corals and other fauna in the region (Tissot et al. 2006; Pirtle 2005; Hardin et al. 1994), though other recent video surveys (e.g., Brancato et al. 2007; Tissot et al. in prep) are currently being analyzed in this context.

San Diego Province

Data analysis of submersible observations from 11 rocky banks off southern California (Tissot et al. 2006) includes the most comprehensive study of fish-invertebrate relationships to date in the province. Densities of gorgonians and black corals were highest in low relief, mixed rock areas including boulders, cobbles, pebbles and sand. Approximately 15% of the 135 black corals observed had other organisms lying on or attached to them and epifauna were mostly crinoids (6.8%) followed by sponges (3.1%). Only 1.3% of all black coral associations involved fishes. None of the 27 observations of gorgonians showed evidence of epifaunal associations. Fish species exhibiting higher frequencies of occurrence near large corals and sponges than elsewhere along transects included cowcod (*Sebastes levis*; median distance = 5.5 m), bank rockfish (*S. rufus*; 1.0 m), swordspine rockfish (*S. ensifer*; 1.3 m), shortbelly rockfish (*S. jordani*; 1.5 m), pinkrose rockfish (*S. simulator*; 1.7 m) and other members of the rockfish subgenus *Sebastomus* (1.4 m). Most of these species including cowcod, bank rockfish and several members of the subgenus, *Sebastomus*, have been targeted commercially. Although these six fish species and large invertebrates co-occurred in similar habitats, the authors questioned the existence of functional relationships because the median distances between them were not small (1.0-5.5 m). In addition to fishes, black corals (*Antipathes* sp.) were observed in association with crinoids, sponges, crabs, basketstars, brittlestars, anemones, algae and salps.

Hardin et al. (1994) examined the spatial distributions of epifauna on both low- and high-relief hard bottom features off Pt. Conception. The second-strongest positive correlation reported between two taxa was that of the cup coral, *Desmophyllum dianthus* and the colonial scleractinian, *Lophelia pertusa*. Moderately positive correlations existed between two other cup corals – *Paracyathus stearnsii* and *Caryophyllia* sp. Other associations with *D. dianthus* included galatheid crabs and anemones (e.g., *Amphianthus californica*). The authors suggest that these correlations, while statistically significant, are most likely due to common affinities to the physical attributes of their habitat (depth, relief, orientation to currents), and not indicative of any functional relationships among taxa.

Oregon Province

At Cordell Bank, Pirtle (2005) examined relationships between structure-forming megafaunal invertebrates and demersal fishes. During submersible dives at water depths from 55 to 250 meters, gorgonians were observed in mixed rock habitats of varying relief while pennatulaceans (*Ptilosarcus* sp. and members of suborder Subselliflorae) occurred in low-relief habitats of mud and bedrock. Widow (*S. entomelas*), rosy (*S. rosaceus*) and unknown juvenile rockfish, adult *Sebastomus*, black-eyed gobies and combfishes were observed more often near gorgonians than expected by chance in habitats where they occurred. In sand- and mud-dominated habitats, flatfish, poachers, combfishes and greenspotted rockfish (*S. chlorostictus*) were observed near pennatulaceans (*Ptilosarcus* sp.). Greater than half of all associations between gorgonians and fishes were within a distance of 1 m; however, none involved direct physical contact.

Davidson Seamount, in contrast to Cordell Bank, is a much deeper submarine environment. Davidson rises from the surrounding seafloor at 3600 meters water depth to its crest at 1250 meters. Corals were observed here primarily on ridges and often oriented to maximize surface area towards the current (DeVogelaere et al. 2005). Rattails (*Coryphaenoides* sp.) and thornyheads (*Sebastolobus* sp.) were observed adjacent to corals, along with sponges, other corals, sea stars, clams, sea cucumbers and octopi (*Graneldone* sp.). Coral epifauna included polychaete worms, isopods, shrimps, crabs, basket stars, crinoids, brittle stars and anemones.

With the exception of Pirtle (2005), DeVogelaere et al. (2005) and Tissot et al. (in prep), much of the data from underwater surveys in the Oregon Province have yet to be analyzed for species associations with deep corals. Recent *in situ* studies at Davidson Seamount, Monterey Canyon and in the Olympic Coast NMS may elucidate additional species associations. For example, the recent ROV survey of deep-sea

Table 3.3. Ratings of potential fishing gear impacts to deep corals off the U.S. Pacific coast. Each measure of impact is rated as High (H), Moderate (M), or Low (L).

	Measure of Impact			
Gear Type	**Severity of Impact**	**Extent of Impact**	**Geographic Extent of Use in Region**	**Overall Rating of Gear Impact**
Bottom trawls	H	H	H	H
Midwater trawls	L	L	H	L
Demersal seines	L	M	L	L
Bottom longlines & gillnets	M	M	M	M
Pots & Traps	M	L	L	L
Other hook and line	L	L	L	L

coral assemblages at the OCNMS (Brancato et al. 2007) revealed many species of fishes and large invertebrates (e.g. shrimp, brittle stars, crabs) nestled among the coral structures (see also. However, the degree to which corals might contribute to the feeding, growth and reproduction of demersal fishes or provide biogenic structure for other megafaunal invertebrates is largely unknown for most of the Oregon Province.

VII. STRESSORS ON DEEP CORAL COMMUNITIES

Compared to other regions in the U.S., the Pacific coast from California to Oregon has a narrow continental shelf, which may result in coral communities here being more susceptible to coastal activities. Some activities that may adversely effect corals include oil and gas development, deployment of gas pipelines and communication cables, and marine pollution. However, fishing operations, particularly bottom trawling, pose the most immediate and widespread threats to deep coral communities.

Effects of fishing

The temperate, nutrient-rich waters of the California Current support lucrative commercial, tribal and recreational fisheries. Fishing operations in the region are very diverse. A limited-entry trawl fishery operates from the Canadian border south to Morro Bay, CA targeting numerous demersal species both on the shelf and upper slope. Vessel sizes range from 35 to 95 feet and average 65 feet (NWFSC 2006). Off California and Oregon, an open-access fishery targeting nearshore species is comprised of vessels from 10 to 50 feet in length (NWFSC 2007). Charter boats also operate out of numerous coastal ports and target a variety of pelagic and demersal species. Gear types used in the region include bottom trawls, midwater trawls, demersal seines, pots, bottom-set gillnets, bottom longlines and other hook-and-line gear, but bottom trawls are the most widely used and potentially harmful to corals. The degree of impact to corals from fishing operations depends on the physical attributes of their habitat (e.g., sediment type, relief), attributes of the gear (e.g., configuration, mode of operation, footprint) and its geographic extent of use (Table 3.3). These attributes will be detailed in relation to each gear type used in the region.

Bottom trawls

Bottom trawls are the most widely used fishing gear off the Pacific coast. They are used off Oregon and in federal waters off Washington and California to target numerous species of demersal fishes, shrimp, prawns, sea cucumbers and sea urchins. Bottom trawls also have the greatest severity ranking of all gear types used in the region (Morgan and Chuendpagdee 2003). Gear components that contact the seafloor include the doors, bridles, footrope (except in shrimp trawls) and occasionally the netting (PFMC 2005). Gear configurations depend on target species and operating depths, with door separation distances ranging from 34-50 m for shelf trawls and 50-200 m for slope trawls (PFMC 2005). Footrope lengths commonly range from 15-34 m for shelf fisheries. Due to their weight and speed (1.5-2.5 knots) over the seafloor, all trawl components that contact the seafloor have the potential to snare, undercut or topple emergent structures, including deep corals. The Pacific Council Groundfish Essential Fish Habitat (EFH) Environmental Impact Statement (EIS) identified sensitivity of coral habitats to trawl gear as relatively high

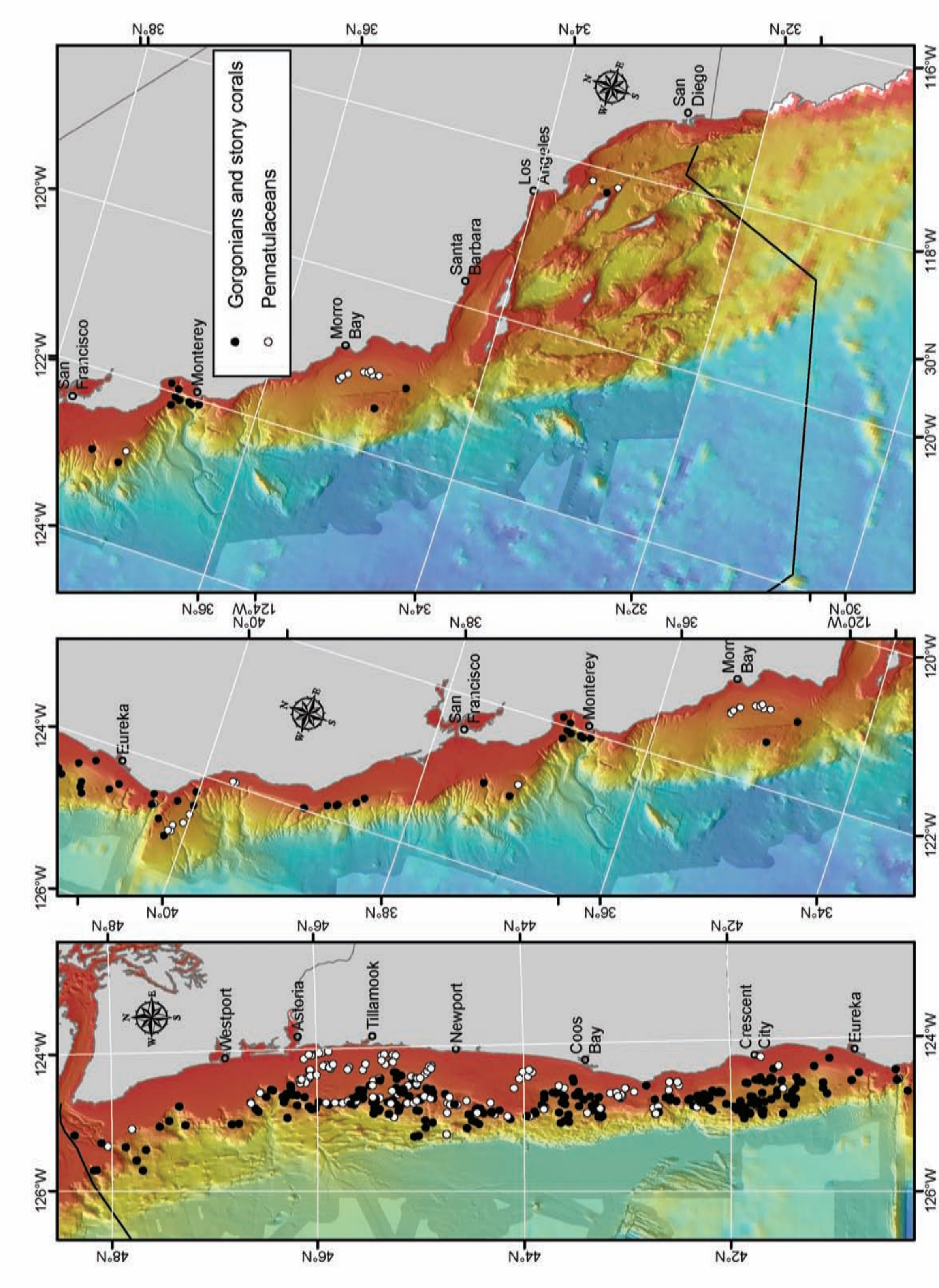

Figure 3.10. Map showing locations of deep coral bycatch recorded by fishery observers in the West Coast Groundfish Observer Program. All observed trips and gear types from August 2001 – August 2004 were queried. Due to limitations of specific identifications, coral bycatch was grouped into two classes: 1) gorgonians and stony corals, and 2) pennatulaceans. Point symbols represent start locations of bottom trawls or longline and pot sets.

(2-3) on a scale of 0-3 with three defined as "major changes in bottom structure, such as re-arranged boulders; large losses of many organisms with differences between impact and control sites greater than 50% in most measured metrics." Furthermore, bottom trawls accounted for over 92% of observed coral bycatch in the region between August 2001 and August 2004 (Figure 3.10). Because bottom trawls are used extensively throughout the region and deep coral habitats are particularly sensitive to these gears, they were given a high rating of impact (Table 3.3).

Midwater trawls

Midwater trawls are used extensively in the

Oregon Province to target Pacific hake (*Merluccius productus*). Hake is a schooling, pelagic species and therefore vessels using midwater trawls try to avoid contact with the seafloor. As evidenced by no records of coral bycatch from this gear type between August 2001 and August 2004 and their very low rating of habitat impact (Morgan and Chuendpagdee 2003), midwater trawls have low impacts to deep coral communities in the region (Table 3.3).

Demersal seines

Demersal seines, also known as Scottish seines, are used in nearshore and shelf areas to catch flatfish (e.g., sand dabs, Petrale sole, English sole) and chillipepper rockfish (PFMC 2005). Demersal seines use a large net attached to long (hundreds of meters) ropes to herd fish on the seafloor. In contrast to trawl gear, their lighter weight and slower movement over the seafloor cause little disturbance (PFMC 2005). Corals most likely to be impacted by this gear are pennatulaceans, because demersal seines are used in areas of unconsolidated sediments where pennatulaceans inhabit. Due to their limited use in the region; however, demersal seines were given a low rating of impact (Table 3.3). Furthermore, there are no records of deep coral bycatch from this gear type.

Scallop dredges

Although dredges were once used to target weathervane scallops, they are now prohibited in the region.

Bottom longlines and gillnets

Bottom-set gillnets are prohibited offshore Washington and Oregon and in California state waters. In federal waters off California, gillnets are used to catch white seabass, bonito, flying fish, white croaker, angel shark, California halibut, lingcod, mullet and perch (PFMC 2005). Bottom longlines, on the other hand, are used throughout the region to target sablefish, rockfish, Pacific halibut, cabezon, lingcod or dogfish. Bottom longlines are composed of weights, hooks and a mainline that contact the seafloor. Gillnets are anchored by weights and leadlines, which weigh about 100 pounds per 100 fathoms of line (PFMC 2005). These gears can travel significant distances over the seafloor, particularly during retrieval when the vessel is not directly over the gear, snaring or undercutting emergent structures (e.g., corals). According to Morgan and Chuendpagdee (2003), bottom longlines and gillnets have a medium to low impact on the physical and biological components of habitat. Furthermore, from August 2001 through August 2004, gillnets and longlines accounted for less than 4% of all observed coral bycatch. However, this low percentage may reflect a sampling bias to mobile gears or that corals damaged by these gears do not reach the surface. Lost longline gear has been observed on the seafloor at several sites within the Olympic Coast NMS (Hyland et al. 2004; Brancato et al. 2007). Nevertheless, sensitivity of coral habitats to hook and line gear (e.g., longlines) was classified as low to moderate (0.3-1.3) on a scale of 0-3 (PFMC 2005). Due to this low to moderate sensitivity rating, medium to low habitat impact rating, and their moderate use in the region, bottom longlines and gillnets were given a medium rating of overall impact (Table 3.3).

Other fishing gears

Throughout the region, pots (also called traps) are used to catch sablefish, Dungeness and other species of crab, spot prawns, spiny lobster and other finfish. Pots can be single (e.g., Dungeness crab) or in a series of up to 50 attached to a groundline (e.g., sablefish) (PFMC 2005). The effect of pots on the seabed depends on their weight, shape and lateral movement during retrieval. If the vessel is not directly above the pot being retrieved, significant contact with the bottom can occur; however, this movement is typically minimized so as not to put excessive strain on the line and other equipment (PFMC 2005). Severity of impact to coral habitats by pots and traps was ranked as low to moderate (PFMC 2005; Morgan and Chuendpagdee 2003). Factoring in their limited use in the region, pots were given a low overall rating of impact (Table 3.3).

In addition to longlines, other types of hook and line gear (e.g., stick gear, rod and reel, jig gears and vertical longlines) are used in the region, but their impacts to deep corals are most likely minimal. Sinkers, hooks and lines can snare and damage corals, but the area of seafloor contacted is small relative to trawls and dredges. Consequently, these hook and line gears were given a low rating of impact (Table 3.3).

Effects of other human activities

In addition to fishing operations, sedimentation caused by oil and gas development has been shown to be detrimental to corals in the region. Other human activities that may adversely impact corals include the deployment of gas pipelines and communication cables and pollution. Unfortunately, little is known about these potential stressors but they are likely to have only localized impacts, if any. In the future, global climate change has the potential to adversely impact corals throughout the Pacific Ocean and in other parts of the world.

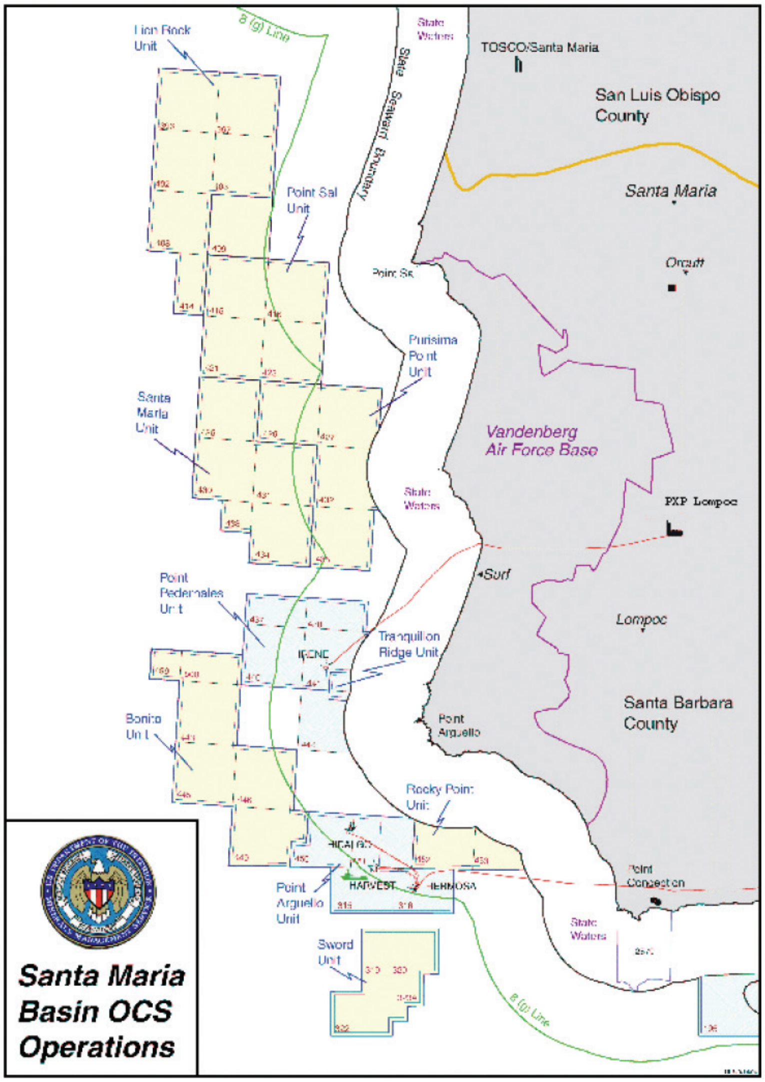

Figure 3.11. Map showing locations of oil and gas leases, platforms and associated pipelines in the Santa Maria Basin off Pt. Arguello, California. Image source: MMS Pacific OCS Region.

Oil and Gas Exploration and Extraction

Since 1958, production of oil and gas has occurred from offshore platforms in southern California. A total of 26 platforms (23 in federal waters, 3 in state waters) are currently sited off Pt. Arguello, San Pedro and in the Santa Barbara Channel at water depths ranging from 11 to 363 m (Love et al. 2003, Figures. 3.11-3.13). A permanent moratorium is currently in place on new oil and gas leases in California state waters, and a moratorium on new leases in federal waters is in affect until 2012 (John Romero, MMS, pers. comm.). No restrictions are in place for existing lease sites, although no platforms have been erected since 1989 (Nevarez et al. 1998). As of 1 May 2006, 1290 total wells had been drilled at the 23 platforms in federal waters. In 2005, 43 of 79 active leases were producing and 23 development wells were spudded (MMS 2006). One potential threat to corals and other filter-feeding organisms from offshore oil and gas operations is through the introduction of suspended or re-suspended materials (Cimberg et al. 1981; Raimondi et al. 1997; NOAA 2004). During drilling, a mixture of water, clay, and barite is pumped down the well hole primarily to cool the equipment and dislodge any rocks. Hyland et al. (1994) documented the abundance of hard-bottom epifauna before, during and after drilling began at three platforms. They found a decrease in the density of four invertebrate taxa, including *Caryophyllia* sp., after drilling began.

Deployment of Gas Pipelines and Communication Cables

Numerous gas pipelines connect offshore production platforms to shore side facilities in southern California (Figures. 3.11-3.13). In addition, cable routes transect many parts of the continental margin off all three west coast states. Recent cable installations include the Alaska United Fiber System – West, which extends from Warrenton, Oregon west-southwest over the shelf and is buried down to 1500 meters water depth. A reinstallation of a communication cable that connects the U.S. and Japan via the northeastern portion of the Olympic Coast NMS was completed in September 2006 (Mary Sue Brancato, Olympic Coast NMS, pers. comm.). Future cable laying operations include the NEPTUNE cable system – a regional cabled ocean observatory in the

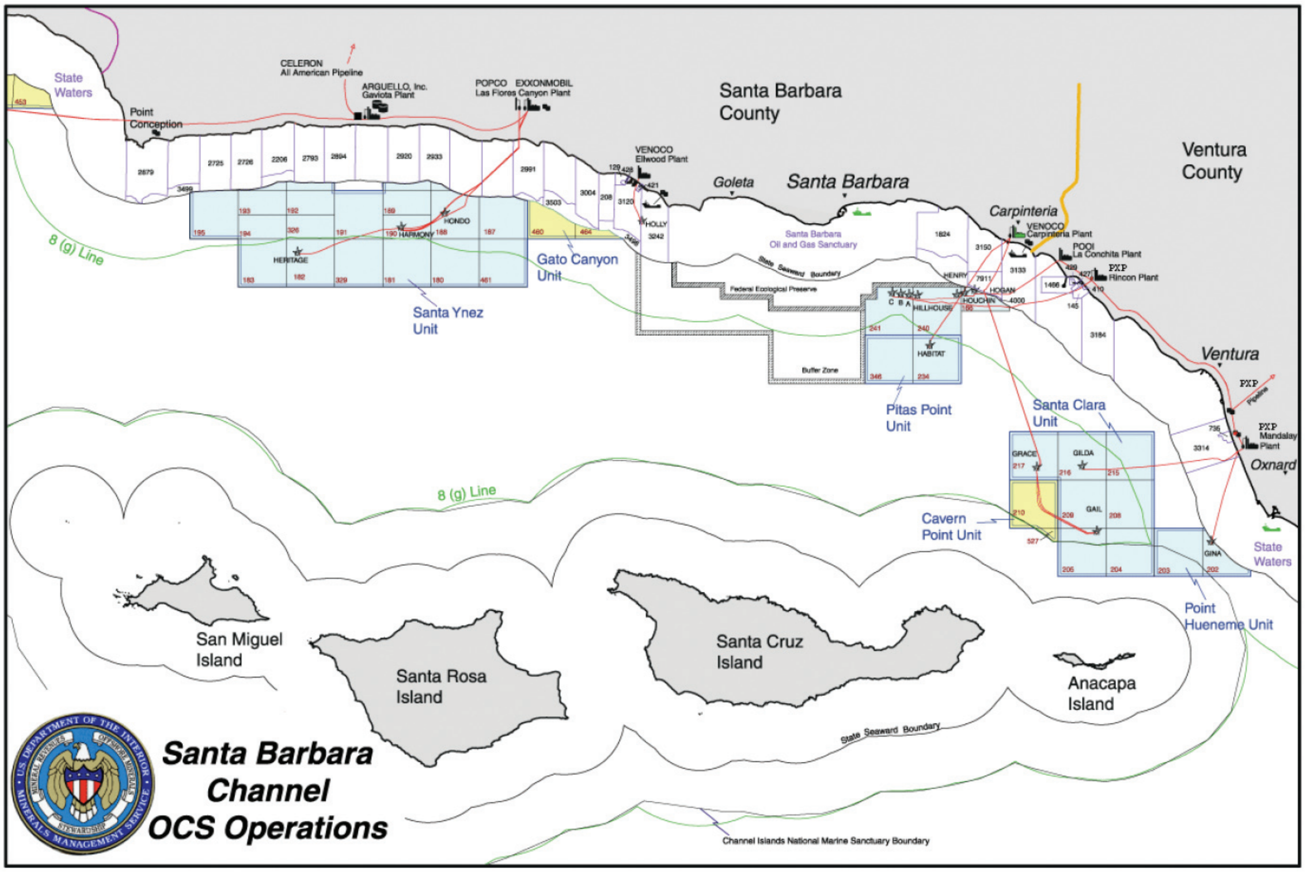

Figure 3.12. Map showing locations of oil and gas leases, platforms and associated pipelines in the Santa Barbara Channel off southern California. Image source: MMS Pacific OCS Region.

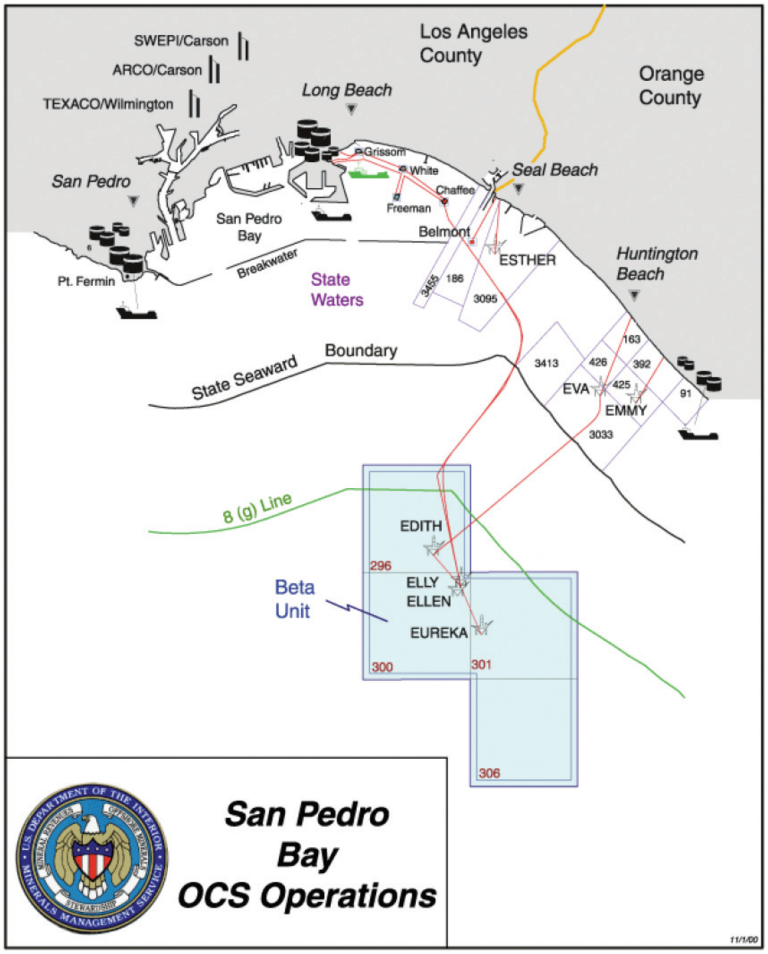

Figure 3.13. Map showing locations of oil and gas leases, platforms and associated pipelines off San Pedro, California. Image source: MMS Pacific OCS Region.

northeast Pacific Ocean. NEPTUNE will consist of a 3000-km network of fiber-optic cables with about 20 instrumented nodes located along the route (Figure 3.14). Portions of the cable network off Vancouver Island, BC are under construction, with the U.S. portion to be installed later.

There have been no reports in the region of communication cables or gas pipelines transecting areas of known coral habitat. However, this may be due to a lack of effort on this topic. Where feasible, cables and pipelines are buried down to deep-water depths (usually 1500 m) to avoid interactions with commercial fishing operations. If corals were located nearby, they could be buried or smothered by resuspended sediments. Where cables and pipelines transect hard-bottom seabed, they cannot be buried and therefore may cause severe impacts to corals if present in the area. Damage can occur along the cable or pipeline itself or over larger swaths by the heavy anchors often used during placement or repair (Freiwald et al. 2004).

Sedimentation

Studies throughout the world report negative effects of sedimentation on corals (Dodge et al. 1974; Dodge and Vaisnys 1977; Dodge and Lang 1983; Hardin et al. 1994); however, some taxa are more vulnerable than others. For example, two experiments have shown that scleractinians have the ability to actively remove sediment from their polyps (Reigl 1995; Shelton 1980), while alcyonaceans rely solely on water motion and gravity (Reigl 1995). Despite this ability by some taxa, sedimentation is still a major threat to the health of coral communities throughout the world (Norse 1993). The U.S. Pacific coast is no exception. At hard-bottom sites off Pt. Conception, CA, Hardin et al. (1994) examined the spatial distribution of epifaunal assemblages in relation to suspended sediment flux. The authors discovered a negative correlation between sediment flux within 2 m of the seafloor and the coverage of filter-feeding organisms that include two stony corals – *Lophelia pertusa* and *Desmophyllum dianthus*.

Natural sources of sediments to the continental margin include coastal rivers – the Columbia being the largest in the region. Studies of sediment deposition and accumulation rates have been conducted at sites off Oregon (Kulm et al. 1975), northern California (Wheatcroft et al. 1997) and central California (Lewis et al. 2002; Eittreim et al. 2002). Although these studies did not specifically address impacts to corals or others filter feeders, they did provide average annual deposition rates over broad ranges of depth and latitude.

Other causes of sediment resuspension include bottom trawling, slumps, storms and turbidity currents (triggered by earthquakes). Bottom trawling may pose the highest risk because of its documented interactions with corals (mostly pennatulaceans and gorgonians in the form of bycatch) and its widespread use in the region. Unfortunately, there is little specific information in the region on the effects of any of these potential causes.

Pollution

The authors are aware of only one study in the region that specifically addressed the effects of pollutants on deep coral communities. Hyland et al. (1994) examined the effects of chemical contaminants from drilling discharges on the benthos off Pt. Arguello, CA. The authors found that concentrations were below toxic levels, suggesting that any biological changes to epifauna were due to increased particulate loading. Because of the lack of information in the region and throughout the world, the effects of pollution on deep corals remain uncertain.

Coral Harvest

Because it retains its pigment after death, *Stylaster californicus* is popular among recreational collectors and has also been harvested commercially for sale in shell shops (NMSP 2005). However, commercial harvest of Stylasterids is now prohibited off California.

Mineral Mining

Compared to oil and gas development, mineral mining has the potential to adversely impact larger areas of seafloor habitat (Carney 2001). Two mining operations have been proposed off the U.S. Pacific coast, but neither has been initiated. Manganese nodules are ores containing minerals including manganese, cobalt, nickel and copper. They were originally discovered during the *HMS Challenger* voyage, although later discoveries of dense aggregations in the central north Pacific provoked economic interest during the Cold War (Carney 2001). Because of the distance and operating depths involved and continued availability of key minerals from

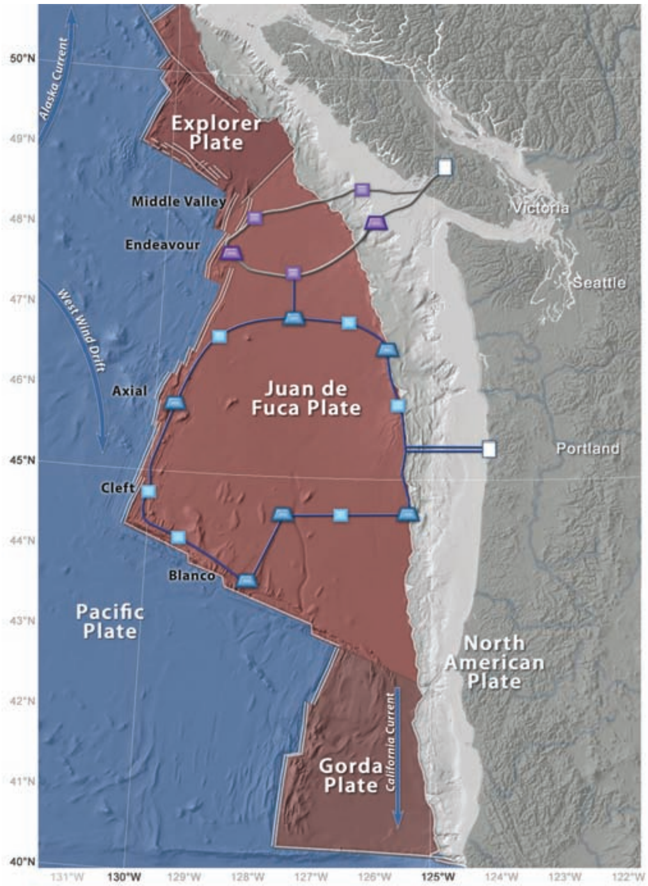

Figure 3.14. Map showing locations of proposed cable routes and node locations for the NEPTUNE project. Image credit:: Debbie Kelley, Univ. of Washington, Center for Environmental Visualization.

terrestrial sources, mining of the nodules was never initiated. These dense aggregations occur outside the EEZ, however, so potential mining operations would not impact U.S. coral resources. The second proposed offshore mining operation was for polymetallic sulfides. In 1983, the U.S. Minerals Management Service issued a draft environmental impact statement for a proposed lease sale of a portion of the seabed on the Gorda Ridge (see Figure 3.2). Despite initial studies as to the impact of mining in the vicinity, there was lack of industry interest. Although it is not known whether corals occur on Gorda Ridge, a photographic study of the proposed lease site in 1986 revealed the presence of other suspension feeders (Carney 2001).

Climate Change

Although oceans are moderating climate change by assimilating anthropogenic CO_2 emissions, it is not without consequence to ocean chemistry. Uptake of atmospheric CO_2 is causing declining pH in ocean surface waters (already 0.1 units lower than preindustrial values) and is predicted to decrease carbonate concentrations in the deep ocean (Orr et al. 2005). Corals use carbonate ions to form skeletal components. Two forms of calcium carbonate are common in the oceans: 1) aragonite, used by scleractinians and most stylasterids, and 2) calcite, used by octocorals and about 10% of stylasterids (Cairns and Mcintyre 1992). Aragonite is more soluble than calcite; therefore its depth of saturation (i.e., aragonite saturation horizon (ASH)) is shallower than that of calcite. Furthermore, the ASH in the north Pacific occurs at shallower water depths than the north Atlantic, resulting in dissolution rates twice as high in the upper 1000 m (Feely et al. 2004). Guinotte et al. (2006) hypothesize that the paucity of deep-sea, bioherm-building scleractinians in the north Pacific is a result of this relatively shallow (50-600 m) ASH. The authors also suggested that stony corals in the north Pacific are already living in marginal aragonite saturation states. Off the U.S. Pacific coast, stony corals are known to occur at water depths down to 578 meters (Cairns 1994). One of the largest accumulations of colonial scleractinian observed thus far in the region (i.e., an extensive low-lying mound of *Lophelia pertusa* at the Olympic Coast NMS) was at a water depth of approximately 250 m (Brancato et al. 2007). Guinotte et al. (2006) predicted that the ASH off the entire U.S. Pacific coast would be shallower than 200 m by 2060, while changes in the calcite saturation horizon will be less pronounced (Orr et al. 2005). If those predictions are correct, the distributions of scleractinians in the region could be severely impacted. Stylasterids would most likely be less affected by changing ASH because they occur at shallower water depths (<183 m).

Evidence suggests that global climate change may pose other threats to corals. Corals are sessile filter feeders, most likely feeding on suspended organic matter that rains down from the surface or is transported by currents (Kiriakoulakis et al. 2005). Because many of the organisms that comprise this source of organic material (e.g., coccolithophores, foraminiferans, pteropods) use carbonate to form protective shells, reduced carbonate concentrations may impact nutrient availability for corals. In addition, rising atmospheric CO_2 is increasing deep-sea water temperatures (Barnett et al. 2005) and altering salinities (Curry et al. 2003), which may in turn cause changes in thermohaline circulation

(Joos et al. 1999). Because corals have evolved in steady-state, nutrient-rich environments, they may be particularly susceptible to such changes in environmental conditions (Guinotte et al. 2006).

Invasive Species

NOAA continues to search for information on the effects invasive species might have on deep corals in the region. Thus far, no specific studies or adverse interactions have been identified.

VII. MANAGEMENT OF FISHERY RESOURCES AND HABITATS

The Pacific Fisheries Management Council (the Council) and the National Marine Fisheries Service (NMFS) are responsible for the management of fishery resources in federal waters off the U.S. Pacific Coast from California to Washington. Fisheries that occur solely within state waters (e.g., pink shrimp in Oregon) are regulated by the individual states, along with other activities that may have impacts to intertidal and subtidal habitats. Other activities occurring within five national marine sanctuaries and on the outer continental shelf are regulated by the NOAA's National Marine Sanctuary Program and the Department of Interior's Minerals Management Service (MMS), respectively. Although specific protections of corals have only been implemented recently, a number of measures adopted by these federal and state agencies have had the indirect effect of coral habitat conservation. These measures will be highlighted below after a brief synopsis of research and mapping programs in the region.

Mapping and Research

A multitude of seabed information exists for the Pacific coast region including swath bathymetric data and sidescan sonar imagery collected during large-scale mapping programs and during targeted geologic investigations, an extensive database of sediment samples collected by the oil industry and during submersible surveys, seismic reflection profiles collected by the oil industry and academic institutions, structural geologic maps created by the state of California, the United States Geological Survey (USGS) and Oregon State University, and photographic and video imagery collected during numerous submersible and ROV surveys. This information was recently used in the creation of a regional map of benthic habitats for the entire continental margin (i.e., intertidal out to ca. 3000 meters water depth) off the Pacific coast (Figure 3.15). Two complimentary projects were commissioned to inform the recent Groundfish EFH environmental impact statement. The Center for Habitat Studies at Moss Landing Marine Laboratories created the map for California (Greene and Bizzarro 2005), while the Active Tectonics and Seafloor Mapping Lab at Oregon State University produced the maps for Oregon and Washington (Goldfinger et al. 2005). The maps show habitat polygons delineating physiographic structures (e.g., shelf, slope and canyons) and surficial lithology (e.g., mud, sand and rock) at horizontal scales ranging from tens of meters to a kilometer. Habitat types were coded based on a modified version of a deep-water habitat characterization scheme developed by Greene et al. (1999). A unique feature of these maps is an associated layer of data quality that quantifies data density and ranks data sources for their utility to habitat mapping (Romsos et al. in press). From these habitat maps, rocky habitats are estimated to comprise approximately 9% (21,000 km^2) of the seafloor area out to ca. 3000 meters water depth.

Several federal and state agencies and academic institutions have conducted additional targeted seafloor mapping projects off the Pacific coast to provide base maps for a variety of benthic habitat investigations. Study areas that have incorporated underwater observational platforms (e.g., camera sleds, submersibles, ROVs) with remote geophysical mapping techniques (e.g., sidescan and multibeam sonar, seismic profiling, laser line scan) include several rocky banks and outcrops off southern California, the Big Sur coast, Davidson Seamount, Monterey Canyon, Cordell Bank, rocky banks on the outer shelf and reefs along the Oregon coast, Astoria Canyon, and hard bottom seafloor features in the Olympic Coast NMS (Figure 3.16). Olympic Coast NMS is also continuing its deep sea habitat mapping program (Intelmann 2006) to guide future ROV survey efforts to document deep coral communities. Many of these investigations have resulted in the discoveries of deep coral communities that were highlighted earlier in this chapter.

To date, there has been no regular monitoring of deep coral habitats in the region. In 2004 and 2006, the Olympic Coast NMS conducted assessments

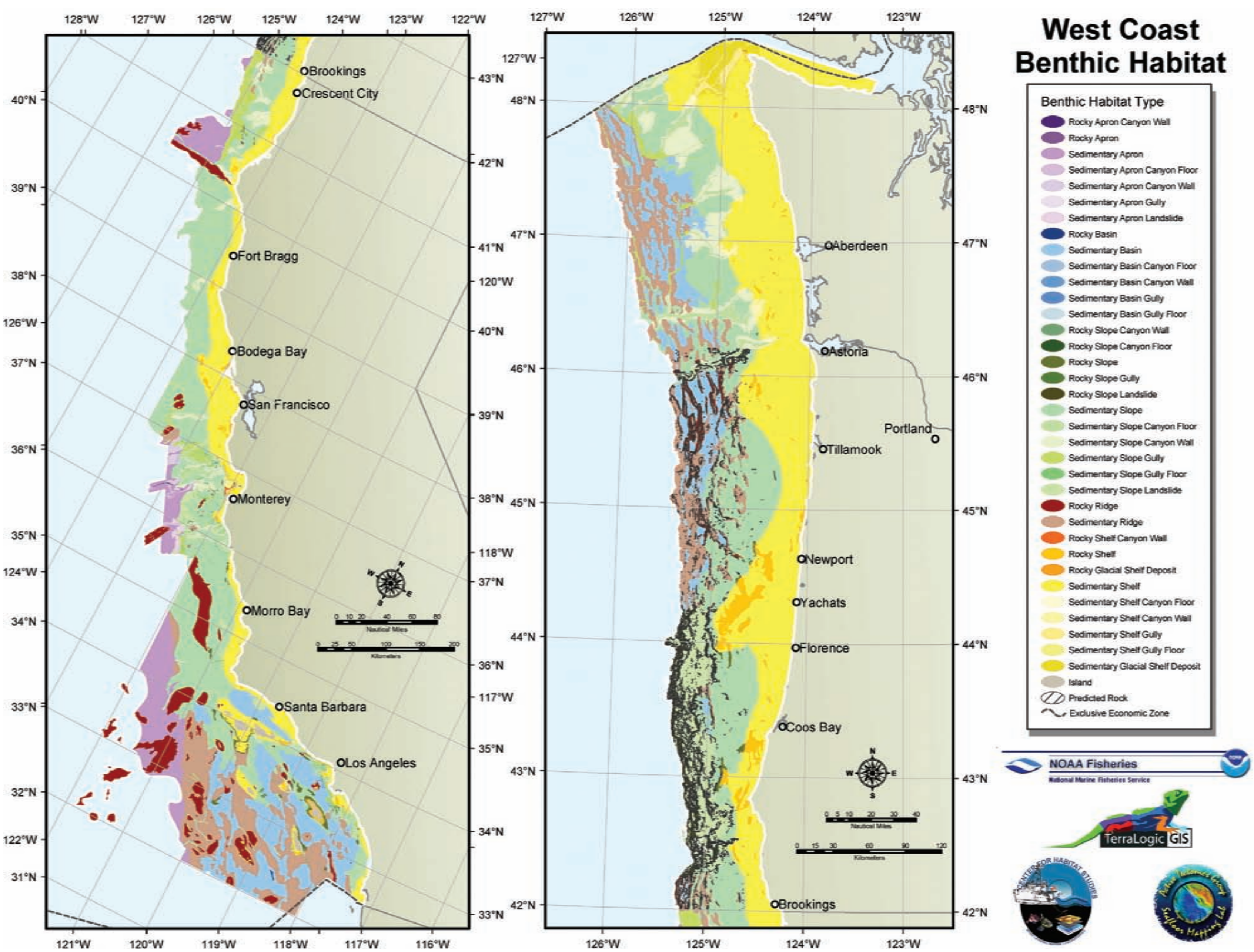

Figure 3.15. Map of Pacific coast of the U.S., showing benthic habitats from the coastline out to approximately 3000 meters water depth. Benthic habitat characterization was modified after Greene et al. (1999) and incorporates information on seafloor lithology (e.g., sedimentary or rocky) and physiography (e.g., shelf, slope, basin, canyon wall). Maps of Washington and Oregon habitats were created the Active Tectonics and Seafloor Mapping Lab at Oregon State University. Map of California habitats was created by the Center for Habitat Studies at Moss Landing Marine Laboratories.

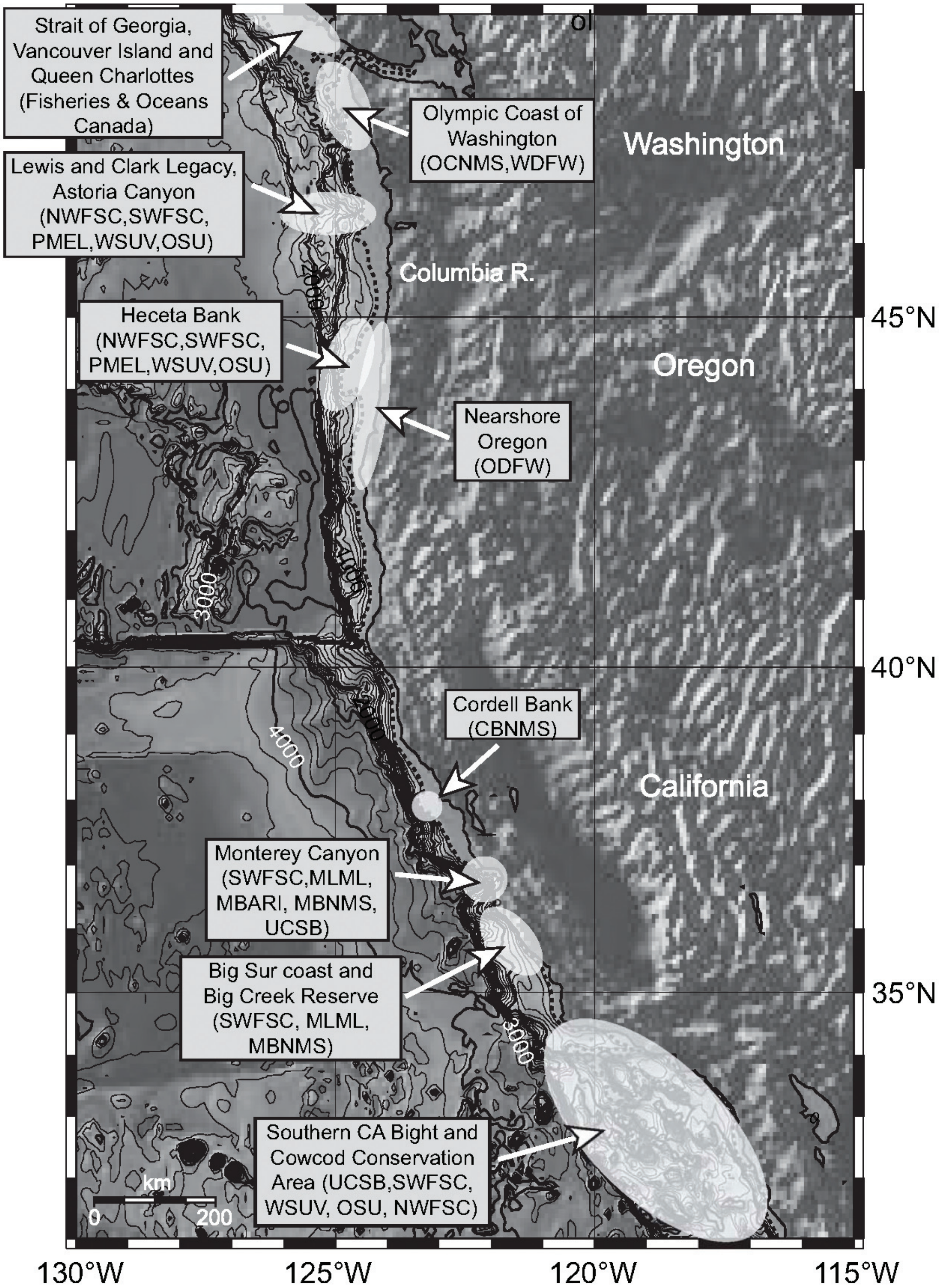

Figure 3.16. Map of the Pacific coast of the U.S., highlighting growing network of study areas and some of the participating organizations conducting interdisciplinary studies of fish habitat (WDFW, Washington Department of Fish and Wildlife; OCNMS, Olympic Coast National Marine Sanctuary; NWFSC, Northwest Fisheries Science Center; SWFSC, Southwest Fisheries Science Center; PMEL, Pacific Marine Environmental Laboratory; WSUV, Washington State University, Vancouver; OSU, Oregon State University; ODFW, Oregon Department of Fish and Wildlife; CBNMS, Cordell Bank National Marine Sanctuary; MLML, Moss Landing Marine Laboratories; MBNMS, Monterey Bay National Marine Sanctuary; and UCSB, University of California, Santa Barbara). Image source: Wakefield et al. 2005, Figure 3.

of deep coral and sponge communities, but it is unclear how future fiscal environments will affect regular monitoring efforts. The Southwest Fisheries Science Center (SWFSC) often conducts submersible surveys of hard-bottom habitats off California. Although the primary focus of these surveys is groundfish habitats, they often occur in areas where corals are located and have therefore resulted in important discoveries, including that of the newly described black coral, *Antipathes dendrochristos*. Other surveys by the Northwest Fisheries Science Center (NWFSC) such as those utilizing AUVs are just being developed as a routine method for groundfish and may provide more routine monitoring of deep coral habitats coastwide.

Directed Harvest

Presently, there is no directed harvest of corals in the region.

Minerals Management Service

The United States Minerals Management Service (MMS) is responsible for the regulation of development and extraction of offshore energy resources, and they regularly conduct research in the Pacific outer continental shelf region. Mitigation of potential impacts to the nearby marine environment from oil and gas development has been a priority of MMS since oil production began of southern California in 1958. Because of the potential risks from offshore oil and gas operations, MMS developed anchoring guidelines to minimize impacts to hard-bottom communities. These guidelines were crafted as a result of numerous studies conducted before and after drilling projects (Mary Elaine Helix, MMS, pers. comm.). In addition, a long-term monitoring program was conducted in the late 1980s to evaluate environmental impacts of oil and gas development on marine and coastal resources (Steinhauer and Imamura 1990). It was these studies that provided some of the first *in situ* observations of stony corals in the region including *Lophelia pertusa*, *Desmophyllum dianthus* and *Paracyathus stearnsii*.

Fishery Management Councils

The Pacific Fishery Management Council, in cooperation with NMFS, has implemented a comprehensive plan to protect EFH for groundfish (see PFMC 2005, 2006). The plan was developed in collaboration with NGOs, the fishing industry, and the National Marine Sanctuary Program to focus largely on pristine or untrawled habitat and biogenic habitats such as corals that are vulnerable to impact from human activities. The plan is considered comprehensive because it addresses impacts from the full range of human activities (fishing and non-fishing), and includes procedures for adaptation as new information becomes available.

Management measures to minimize adverse impacts from fishing include marine protected areas, reductions in fishing effort, and gear restrictions as recommended by the National Research Council (NRC 2002). Over 130,000 mi^2 (336,700 km^2) are now marine protected areas (MPAs) and fully protected from impacts from bottom trawls, with selected vulnerable habitats protected from all fishing gears that contact the bottom (Figure 3.17). The MPAs are distributed the length of the coast and include both federal and state waters. The MPAs work in concert with other spatial management actions taken by the Council such as the Rockfish Conservation Areas and Cowcod Conservation Areas (Figure 3.18) that have significantly reduced fishing effort in habitats important to the adult life-stage of some overfished species. Some of these habitats are hard-bottom areas that may include deep corals. Fishing effort has also been significantly reduced off the central California coast through a collaboration of the fishing industry and the Nature Conservancy. A feature of this collaboration is the private purchase of trawl fishing permits by the Nature Conservancy. Finally, gear restrictions implemented by the Council include coast wide prohibitions on gear types known to have a high impact on benthic habitats. Prohibited gears include dredge gear, beam trawl and large footrope bottom trawl.

Impacts from non-fishing activities were addressed by the Council through the establishment of Habitat Areas of Particular Concern (HAPC) and publication of recommended conservation measures (PFMC 2005). NMFS is now using the HAPC to focus their conservation efforts related to non-fishing activities through the EFH consultation process.

The Council and NMFS recognized that the plan to protect groundfish habitat is, in large part, based on precautionary management principles due to important gaps in available information. To accommodate the likelihood that new information

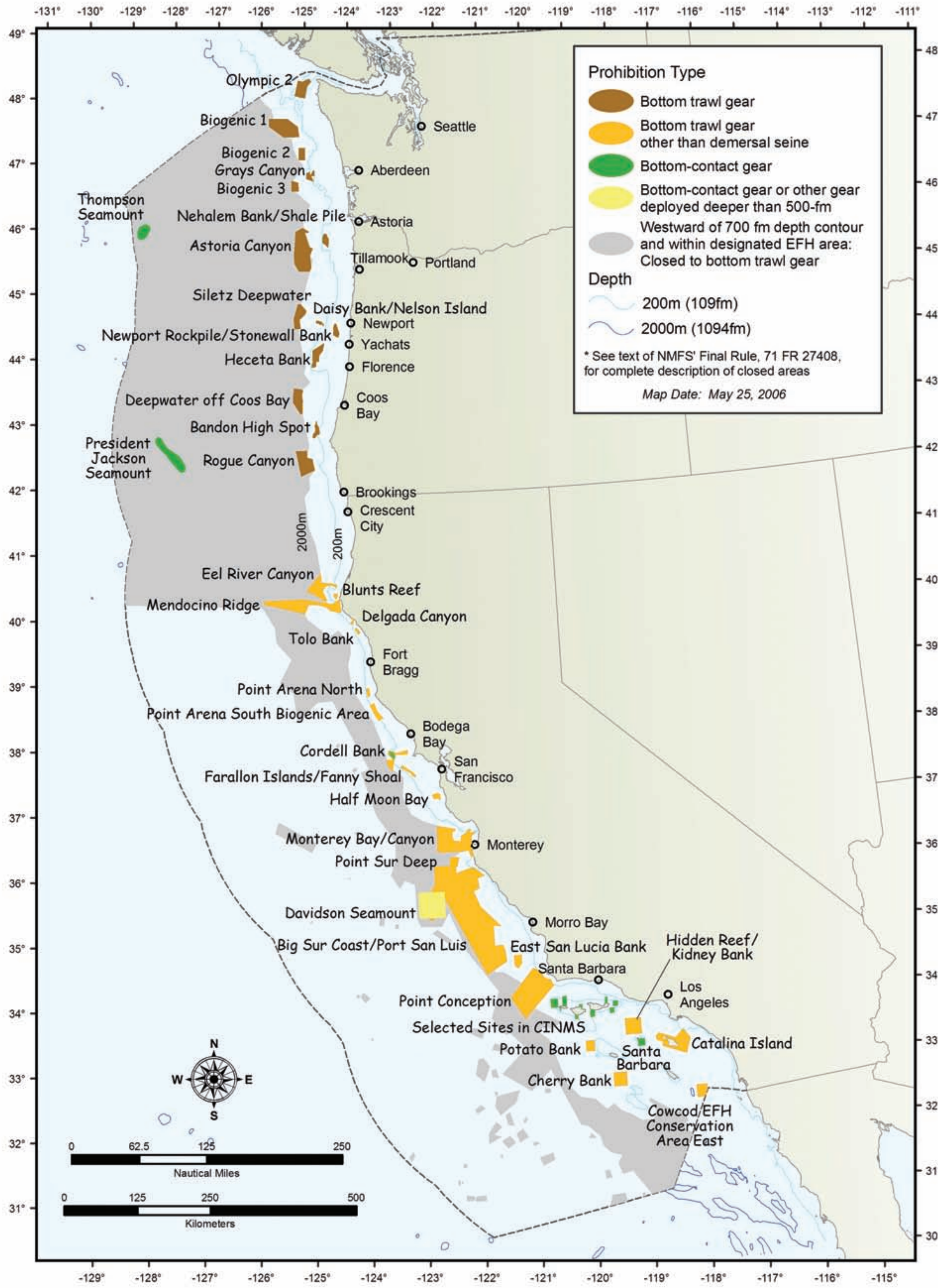

Figure 3.17. Map showing locations of conservation areas specified in Amendment 19 to the Pacific coast Groundfish fishery management plan. Conservation areas were developed in the Pacific Coast Groundfish Essential Fish Habitat EIS as part of the preferred alternative to minimize adverse impacts to EFH. Image source: PFMC 2006.

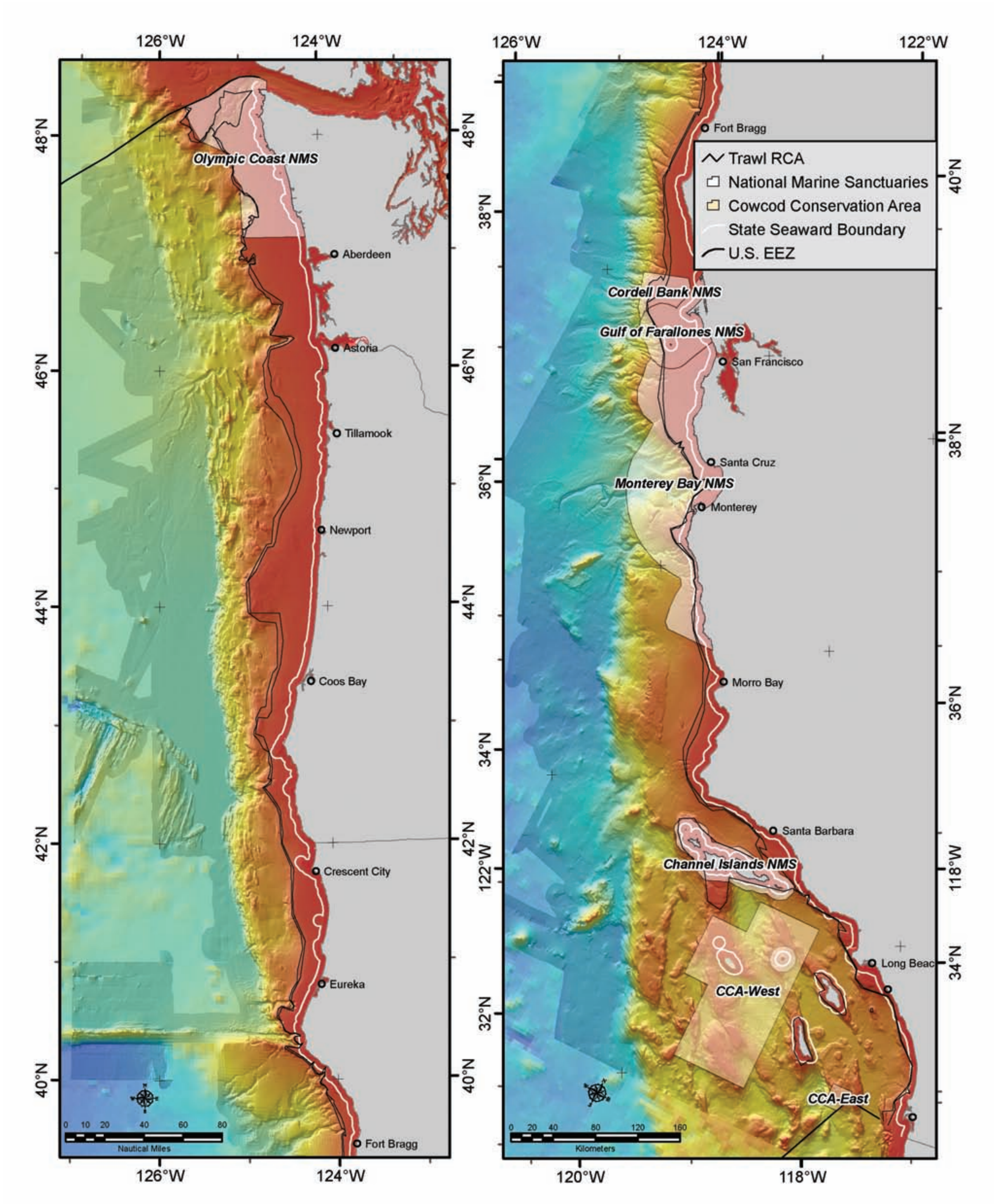

Figure 3.18. Map showing locations of some federal marine managed areas off the U.S. Pacific Coast, including national marine sanctuaries, the Cowcod Conservation Areas (CCA) and the trawl Rockfish Conservation Areas (RCA). The boundaries of the trawl RCA are adjusted on two-month management cycles in response to bycatch information on overfished species. Shoreward boundaries can be as shallow as the shoreline while seaward boundaries can be as deep as 250 fathoms. An area between the lines approximating the 100- and 150-fathom isobaths (shown on map) has been permanently closed to bottom trawling since inception of the trawl RCA in 2002.

will become available through research, the Council established a streamlined process to adapt habitat protection measures.

In the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 (P.L. 109-479), Congress directed NOAA to implement a Deep Sea Coral Research and Technology Program and allowed the designation of deep coral zones. The Deep Sea Coral Research and Technology Program will identify, locate and map locations of deep sea corals, monitor activity in locations where deep sea corals are known or likely to occur, conduct research and develop technologies to assist fishing industry participants in reducing interactions between fishing gear and deep sea corals. The Councils have discretionary authority to designate zones for the protection of deep sea corals in areas where deep sea corals have been identified by the Deep Sea Coral Research and Technology Program.

National Marine Sanctuaries

In the Pacific region there exist five national marine sanctuaries. The Olympic Coast NMS is located off northern Washington, while the other four sanctuaries, Cordell Bank, Gulf of the Farallones, Monterey Bay, and Channel Islands are located off central and southern California (Figure 3.18). Except in designated marine reserves or conservation areas, the sanctuaries do not regulate fishing including the use of bottom contact gears. All sanctuaries, however, prohibit other activities that may be harmful to corals, including but not limited to 1) new oil, gas or mineral exploration, development and production, 2) discharge of materials or substances except fish parts, bait, water or other biodegradable effluents, and 3) alteration of the seabed except for normal fishing activities and anchoring. In addition, the Cordell Bank NMS prohibits the removal or injury of benthic organisms in waters above 50 fathoms (91 m), except during normal fishing operations outside of designated conservation areas.

In May 2007, the National Marine Sanctuary Program established a network of marine reserves and one conservation area within the Channel Islands NMS (Figure 3.19) to complement an existing network of state reserves implemented in April 2003 by the state of California (Figure 3.19). After implementation in July 2007, the new federal reserves and conservation area will total 110.5 nmi^2 and 1.7 nmi^2, respectively. The state of California is expected to extend the boundaries of it's existing reserves to the three mile state-federal waters boundary, thereby increasing to total area of reserves and conservation areas to 232 nmi^2 and 8.6 nmi^2, respectively. Like existing state reserves, all extractive activities will be prohibited while certain fishing for lobster and recreational take of pelagic fishes will be allowed in conservation areas (15 FR 29208). Proposed

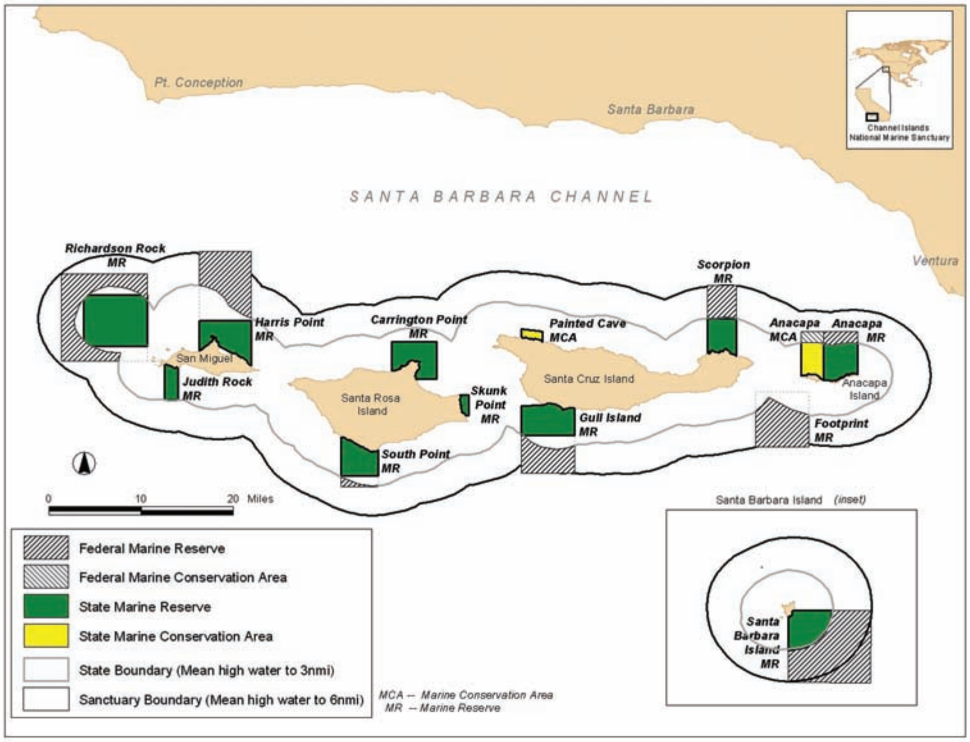

Figure 3.19. Map showing location of the Channel Islands National Marine Sanctuary (CINMS) and its network of marine protected areas. State MPAs were implemented in April 2003 while federal MPAs will be implemented in July 2007. Image source: Channel Islands NMS.

rules for marine zoning in the Monterey Bay and Cordell Bank NMS are expected in the near future.

State activities

The state of California in recent years has enacted a series of laws to direct the management of state marine resources, including the Marine Life Management Act (Stats. 1998, ch. 1052), the Marine Life Protection Act (MLPA, Stats. 1999, ch. 1015), and the Marine Managed Areas Improvement Act (Stats. 2000, ch. 385). In particular, a key mandate of the MLPA is to design and manage a network of MPAs to protect marine life, habitats, ecosystems, and natural heritage while providing recreational, educational and study opportunities. In addition to the marine protected areas implemented in 2003, the state, in April 2007 adopted a network of 29 MPAs for their Central Coast Study Region, which encompasses state waters between Pt. Conception and Pigeon Point (Figure 3.20). These include new and expansions of existing MPAs that cover approximately 204 mi^2 (528 km^2) or 18% of state waters in the central coast region, including 97 mi^2 (251 km^2) of no-take reserves (Office of Administrative Law Notice File Number Z06-1031-05). While corals (specifically hydrocorals) are listed as "benefit species" for only three of the MPAs, the protection of both shallow and deep hard bottom habitats is an objective for this network of MPAs. Planning and scoping of additional MPAs began in early 2007 for the next study region, the North Central Coast, which encompasses state waters from Pigeon Point north to about Pt. Arena.

To date, only about a third of the seafloor in California state waters has been mapped at any appreciable scale (Rikk Kvitek, CSUMB, pers. comm.). The Seafloor Mapping Lab of California State University Monterey Bay (CSUMB) and its partners are currently engaged in the North Central Coast Mapping Project, which will produce multibeam base maps for state waters seaward of the 20-meter isobath from Año Nuevo north to Pt. Arena. Another project mapping the coastal area in the Santa Barbara Channel involves the Seafloor Mapping Lab, USGS and the California Ocean Protection Council. Over the next 5-6 years, the California Coastal Conservancy and Ocean Protection Council hope to complete comprehensive mapping for the remaining 66% of state waters (Rikk Kvitek, CSUMB, pers. comm.). The time frame for completion will depend on available funds.

Oregon also suffers from lack of seabed information in state waters. To date, less than 5% of Oregon's ca. 950 nm^2 (3263 km^2) territorial sea is mapped. In March 2006, a consensus statement, signed by 20 Oregon marine scientists, called for support and funds to map the seafloor within Oregon's territorial sea. Projected costs are under $6 million. Stated reasons for this mapping plan include management of hazards posed by tsunami events, describing nearshore habitats on which nearshore fisheries and marine resources depend, and scientific support of two gubernatorial proposals – establishment of a limited network of marine reserves in state waters, and a national marine sanctuary to be sited off Oregon. In response to the scientific consensus statement, the Territorial Sea Mapping Bill (HB 2924), which would appropriate funds for seafloor mapping, was introduced in February 2007. Passage of HB 2924 along with the establishment of reserves and a national marine sanctuary are still pending.

In September 2006, the three west coast governors signed a joint agreement to collaborate on critical ocean and coastal protection and management issues. Short-term priorities for this collaboration include increased funding for mitigation of nonpoint source pollution, opposition to oil and gas leasing, exploration and development, and a regional research plan to support ocean observing programs and seafloor and habitat mapping.

VIII. REGIONAL PRIORITIES TO UNDERSTAND AND CONSERVE DEEP CORAL COMMUNITIES

Given the limitations of existing information off the U.S. Pacific coast, it is clear that more targeted data collections and mapping efforts are needed. Because many collections are made from long trawls that can traverse several habitats, it is impossible to determine specifically the habitat from which these species were collected. Therefore, to date, it is difficult to map corals at a regional scale showing the appropriate habitat associations. Furthermore, coral specimens are continuously collected during *in situ* photographic surveys, regional trawl surveys and by fisheries observers. Rapid identification of these samples is

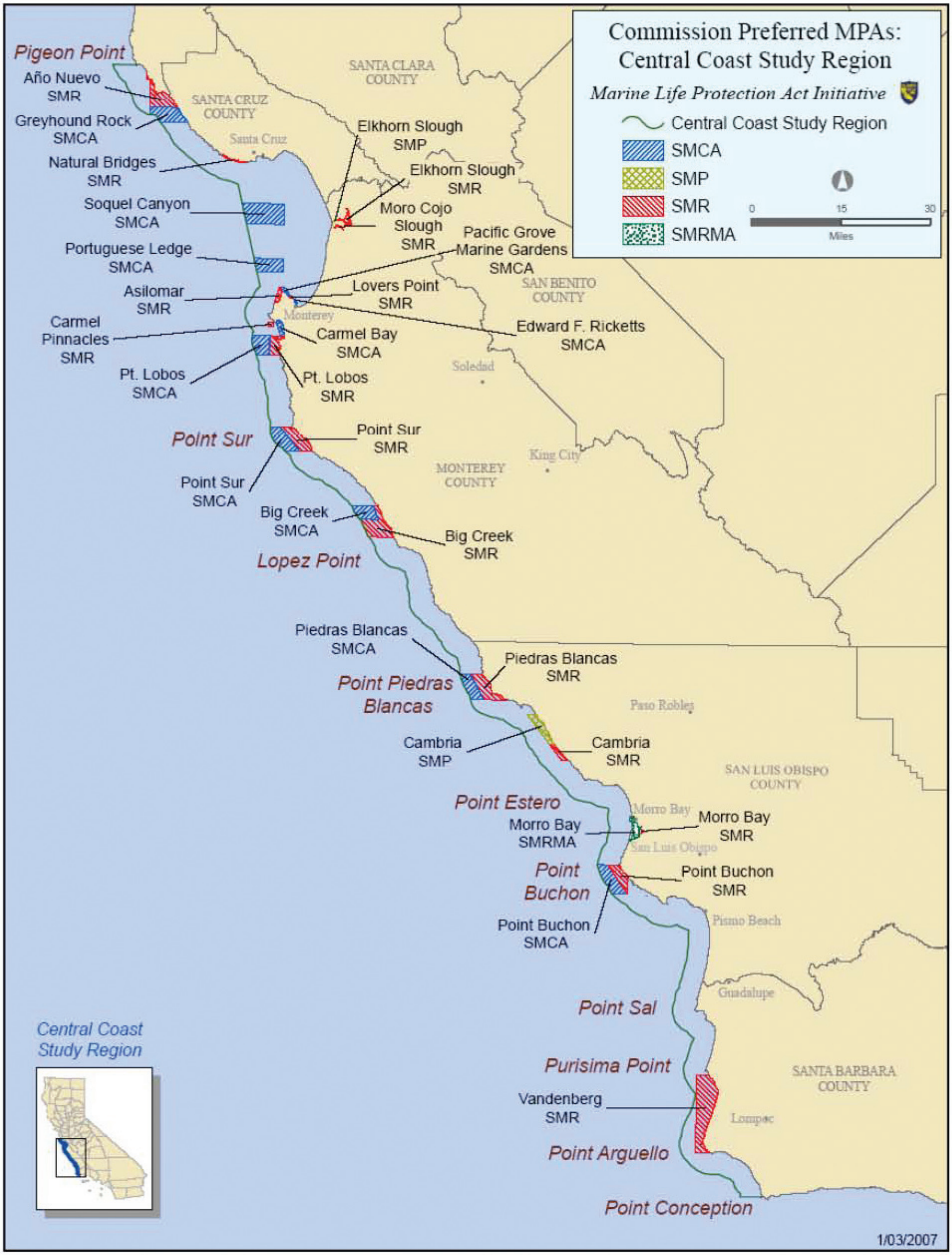

Figure 3.20. Map showing locations of marine protected areas in the Central Coast study region for the state of California, including state marine conservation areas (SMCA), marine parks (SMP), marine reserves (SMR) and marine recreational management areas (SMRMA). Image source: California Department of Fish and Game.

needed to mitigate further impacts to deep corals and their habitats. Finally, the establishment of a network of conservation areas in the region provides an unprecedented opportunity to monitor coast wide recovery of benthic habitats (including those that support coral communities) from fishing impacts.

Mapping

Because little is known about the nature of relationships between corals, other invertebrates and demersal fishes off the Pacific coast, the highest mapping priority is to quantify those relationships. To date, few studies (see Tissot et al. 2006; Pirtle 2005; Hardin et al. 1994) in the region have examined the nature of relationships between corals, other structure-forming invertebrates and fishes, though analysis of recent surveys is ongoing (see Brancato et al. 2007). In order to evaluate the importance of corals to their benthic communities, future *in situ* surveys will need to incorporate a more holistic investigation of species relationships and habitat characteristics.

Surveys are needed that specifically monitor the abundance and distribution of corals in representative habitat types so that accurate and comprehensive maps of their distribution and abundance can be made. Targeted surveys on representative habitats using underwater platforms (e.g., submersibles, ROVs, AUVs) in conjunction with optical survey systems (e.g., video, laser line scan) are needed. Survey areas can be selected using maps of surficial geologic habitats that were developed for the Pacific coast Groundfish EFH EIS (see Figure 3.15) or higher resolution maps of specific areas. In addition, areas of repeated coral bycatch identified during mapping of existing observer and trawl survey data, should be intensively mapped to establish the extent of these “hot spots.”

Research

Coral information can be collected ancillary to other survey and monitoring activities, however it is difficult for non-specialists on these surveys to provide specific identifications. Collaborations with systematics experts at museums through a pilot project in the NWFSC’s Genetics and Evolution Program to develop molecular methods for the rapid identification of Pacific coast corals are already in place. The development of this capability will provide for species-level identification of corals and potentially other difficult to identify structure-forming invertebrates from the region’s ongoing trawl surveys and observer program and will provide validations of identifications during targeted deep coral surveys.

Deep corals are vulnerable to a variety of activities including oil and gas exploration and fishing; however, little is known about the potential recovery rates of these species. There are a variety of ways to monitor recovery. For instance, age and growth information can be obtained through a combination of biochemical studies, ^{14}C and other radiometric dating, stable oxygen isotope data from the corals themselves and other biochemical analyses. In addition to basic age information, it should be possible to associate growth stages of corals to environmental change. Working with biochemists at collaborating academic institutions, the physiological potential for recovery of deep corals via geochemical and biochemical analyses of age and growth as well as growth potential can be investigated.

Other gaps in information result from the fact that few targeted surveys have been conducted in the region. Nearly thirty species of stylasterid corals have been observed in waters off Alaska including the Aleutian Islands coral gardens and parts of the Bering Sea and Gulf of Alaska (Stone and Shotwell, Chapter 2). In contrast, only five species of stylasterids have been observed in the Oregon Province with an additional two species found off British Columbia (Appendix 3.1, Jamieson et al. 2006). This may be a result of sampling bias; nonetheless, more focus needs to be given to the shallower depths where these taxa are commonly found. Also, reef-building scleractinians (e.g., *Lophelia pertusa*) while common in the San Diego Province do not form expansive reefs like those in the north Atlantic. While ocean chemistry may be a factor (see Guinotte et al. 2006; Orr et al. 2005), it’s clear, especially with the recent discovery of a *Lophelia* mound in the Olympic Coast NMS that more attention needs to be given to these taxa.

Although more research on deep coral communities is needed, data mining opportunities do exist. Since the late 1980s, underwater vehicles and camera sleds have been used to survey the benthic environment off the Pacific coast. A product of these surveys is hours upon hours of video data. Review of these videos, while time-consuming, may provide additional observations of deep corals and insights into their ecology (see Strom 2006). A great example of rescuing existing data from past visual surveys of deep corals and other structure-forming invertebrates is a longterm and productive collaboration among fishery biologists at the SWFSC and invertebrate ecologists at Washington State University. This collaboration has resulted in a georeferenced database on the distribution and abundance of deep corals and associated fishes and habitats off California, as well as providing the informational basis for evaluating deep corals as EFH for demersal fishes.

Summary of research priorities:

- Quantify and describe the nature of associations of deep corals with other structure-forming invertebrates and demersal fishes.
- Timely identification of coral specimens collected during region trawl surveys and by fisheries observers.
- Investigate recovery rates of corals and their habitats from a variety of stressors, particularly fishing.
- Focus more survey effort in shallow rocky habitats where corals may be more susceptible to coastal activities.
- Data mining of video records from numerous submersible and ROV surveys of rocky features throughout the region to identify deep corals and any significant habitat and species associations.

IX. CONCLUSION

The Pacific coast from California to Washington hosts a considerable amount of deep coral habitat. Significant coral communities have been discovered at Davidson Seamount (DeVogelaere 2005), in Monterey Canyon, at Cordell Bank (Pirtle 2005), in the Olympic Coast NMS (Brancato et al. 2007) and on numerous rocky banks off southern California (Love et al. 2007; Tissot et al. 2006; Yoklavich and Love 2005), including the recently discovered Christmas tree coral, *Antipathes dendrochristos* (Opresko 2005). Pennatulaceans, black corals and gorgonians have also been recorded coast wide in the catch of bottom trawl surveys and by fishery observers. For the most part, corals in the region do not build reefs with observations of only two reef-building stony corals - *Lophelia pertusa* and *Madrepora oculata* in the San Diego Province and *L. pertusa* in the Olympic Coast NMS. Although associations of corals with other invertebrates and fishes have been reported, there is no direct evidence that any of these represent obligate relationships between taxa. More targeted studies are needed to further investigate and quantify these relationships.

Much of the recent information on the regional zoogeography of higher-level coral taxa was collected during bottom trawl surveys. Some of these surveys are ongoing and will provide continued mapping information within the limitations of the collection methods on these species. More detailed information, but in a limited geographic scope, has been collected using submersibles, remotely operated vehicles (ROVs) and more recently, autonomous underwater vehicles (AUVs); however, these surveys most often focus on demersal fishes, though usually in areas where deep corals are found. Unlike trawl surveys, these *in situ* photographic surveys can provide information on the relationships between deep corals, other invertebrates and demersal fishes. *In situ* photographic surveys provide localized mapping of deep coral habitats but are seldom conducted on a repeated basis, and therefore do not provide routine monitoring of these sites. Additional information on the distribution of corals as well as monitoring fishing impacts can be gleaned from information collected by fisheries observers. Observers currently collect this information on an ongoing basis.

Unique attributes of the region that may influence coral distributions include a narrow continental shelf, coastal upwelling and a large latitudinal extent encompassing two distinct zoogeographic provinces. Unlike the eastern coast of the U.S., the Pacific coast is part of an active continental margin, with both prolonged (e.g., subduction) and episodic (e.g., turbidity currents) events that both shape and impact deep coral habitats. However, the most significant and immediate threat to coral habitats in the region is commercial fishing, namely widespread use of bottom trawls to target demersal fishes. Direct evidence of fishing impacts to corals has been reported by fishery observers. Additional evidence of fishery interactions with the seafloor (e.g., trawl marks in sediments, derelict gear) in the vicinity of corals also is provided from *in situ* photographic surveys, such as those conducted recently in the Olympic Coast NMS (Hyland et al. 2004; Brancato et al. 2007). With recent fishery management measures (e.g., area closures, gear restrictions), however, the risk posed by bottom trawling has been significantly reduced. Although conservation areas encompass many known coral habitats coastwide, recent discoveries of diverse coral communities outside of conservation areas (e.g., in the Olympic Coast NMS) warrant further consideration of protection.

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Appendix 3.1. Taxonomic list of known species of deep corals off the U.S. Pacific Coast, California to Washington. List includes both confirmed taxonomic records and some unconfirmed records of genera identified from surveys using bottom trawls and underwater vehicles. These unconfirmed records are denoted by the genus name followed by the word "species" (abbreviated as "sp"). Occurrence in two zoogeographic provinces (San Diego and Oregon) is noted. Known depth distributions are noted and originate from taxonomic records, published papers, and National Marine Fisheries Service (NMFS) bottom trawl surveys. Other abbreviations include the Olympic Coast (OCNMS) and Monterey Bay (MBNMS) National Marine Sanctuaries.

Higher Taxon	Coral Taxa	San Diego	Oregon	Depth (m)	Source
Phylum Cnidaria					
Class Anthozoa					
Subclass Hexacorallia					
Order Scleractinia					
Family Fungiacyathidae	*Fungiacyathus marenzelleri* Vaughan, 1906	x	x		Cairns (1994)
Family Micrabaciidae	*Leptopenus discus* Moseley, 1881		x		Cairns (1994)
Family Rhizangiidae	*Astrangia haimei* Verrill, 1866	x	x	1-53	Cairns (1994)
Family Oculinidae	*Oculina profunda* Cairns, 1991		x	119 -578	Cairns (1994)
	Madrepora oculata Linnaeus, 1758	x		84	Cairns (1994), Etnoyer and Morgan (2003)
Family Caryophylliidae	*Caryophyllia arnoldi* Vaughan, 1900	x	x	183 - 505	Cairns (1994)
	Labyrinthocyathus quaylei Durham, 1947	x	x	37 - 293	Cairns (1994)
	Crispatotrochus foxi Durham and Barnard, 1952	x		82	Cairns (1994)
	Paracyathus stearnsii Verrill, 1869	x	x		Cairns (1994)
	Paracyathus montereyensis Durham, 1947		x	75 - 146	Cairns (1994)
	Coenocyathus bowersi Vaughan, 1906	x	x	9 - 302	Cairns (1994), NMFS
	Nomlandia californica Durham and Barnard, 1952	x		82	Cairns (1994)
	Desmophyllum dianthus (Esper, 1794)	x	x		Cairns (1994)
	Lophelia pertusa (Linnaeus, 1758)	x	x		Cairns (1994), Etnoyer and Morgan (2003), OCNMS, unpublished data
Family Flabellidae	*Javania californica* Cairns, 1994		x	62 - 170	Cairns (1994)
	Polymyces montereyensis (Durham, 1947)	x	x	69 - 212	Cairns (1994), NMFS
Family Dendrophylliidae	*Balanophyllia elegans* Verrill, 1864	x	x		Cairns (1994), Pirtle (2005)
	Dendrophyllia oldroydae Oldroyd, 1924	x		99 - 366	Cairns (1994)

Higher Taxon	Coral Taxa	San Diego	Oregon	Depth (m)	Source
Order Antipatharia					
Family Antipathidae	*Antipathes dendrochristos* Opresko, 2005	x		90 - 360	Tissot et al. (2006)
	Antipathes sp.	x	x	82 - 1162	NMFS, Etnoyer and Morgan (2003), MBNMS, unpublished data
Family Cladopathidae	*Chrysopathes formosa* Opresko, 2003	x			Opresko (2003)
	Chrysopathes speciosa Opresko, 2003		x	296 - 1400	Opresko (2003), NMFS
	Trissopathes pseudotristicha Opresko, 2003	x	x		Opresko (2003), MBNMS, unpublished data
Family Schizopathidae	*Bathypathes* sp.	x	x	136 - 1243	NMFS, Etnoyer and Morgan (2003), MBNMS, unpublished data
	Lillipathes sp.		x	531 - 1243	NMFS, MBNMS, unpublished data
	Umbellapathes sp.		x		MBNMS, unpublished data
Subclass Octocorallia					
Order Gorgonacea					
Family Acanthogorgiidae	*Acanthogorgia* sp.		x		MBNMS, unpublished data
	Calcigorgia spiculifera Broch, 1935		x	1127 - 1159	NMFS
Family Anthothelidae	*Anthothela pacifica* (Kukenthal, 1913)	x	x		Austin (1985)
Family Chrysogorgiidae	*Chrysogorgia* sp.		x		MBNMS, unpublished data
	Radiceps sp.		x		Austin (1985)
Family Coralliidae	*Corallium* sp.		x	1357 - 2447	MBNMS, unpublished data, OCNMS, unpublished data
Family Gorgoniidae	*Adelogorgia phyllosclera* Bayer, 1958	x	x		Montagne and Cadien (2001)
	Eugorgia rubens Verrill, 1868	x			Montagne and Cadien (2001)
	Heterogorgia tortuosa Verrill, 1868	x			Montagne and Cadien (2001)
	Leptogorgia caryi Verrill, 1868	x	x	129 - 1200	Cairns et al. (2002), NMFS
	Leptogorgia chilensis Verrill, 1868	x	x	86 - 710	Cairns et al. (2002), NMFS, OCNMS
	Stenogorgia kofoidi Nutting, 1909		x		Austin (1985)
Family Isididae	*Acanella* sp.		x		MBNMS, unpublished data
	Isidella sp.	x	x	808 - 1165	NMFS, Etnoyer and Morgan (2003), MBNMS, unpublished data

Higher Taxon	Coral Taxa	San Diego	Oregon	Depth (m)	Source
	Keratoisis flabellum Nutting, 1908		x		Etnoyer and Morgan (2003)
	Keratoisis philippinensis Wright and Studer, 1910		x		Etnoyer and Morgan (2003)
	Keratoisis sp.	x	x	516 - 1707	NMFS, Etnoyer and Morgan (2003), MBNMS, unpublished data
	Lepidisis sp.	x			Etnoyer and Morgan (2003), MBNMS, unpublished data
Family Muriceidae	*Muricea californica* Aurivillius, 1931	x			Grigg (1970)
	Muricea fruticosa Verrill, 1869	x			Grigg (1970)
	Thesea sp. A	x			Ljubenkov (1986), Montagne and Cadien (2001)
	Thesea sp. B	x			Ljubenkov (1986), Montagne and Cadien (2001)
Family Paragorgiidae	*Paragorgia arborea* (Linnaeus, 1758)		x	185 - 1743	Etnoyer and Morgan (2003), MBNMS, unpublished data, OCNMS, unpublished data
	Paragorgia sp.	x	x		Etnoyer and Morgan (2003)
Family Plexauridae	*Swiftia spauldingi* (Nutting, 1909)	x	x		Austin (1985)
	Swiftia beringi Nutting, 1912		x		OCNMS, unpublished data
	Swiftia kofoidi (Nutting, 1909)	x	x		Austin (1985)
	Swiftia pacifica (Nutting, 1912)		x	78 - 1186	NMFS, OCNMS, unpublished data
	Swiftia simplex (Nutting, 1909)	x	x	62 - 1075	Austin (1985), NMFS
	Swiftia torreyi (Nutting, 1909)	x	x		Austin (1985)
Family Primnoidae	*Amphilaphis* sp.	x		114 - 114	NMFS
	Callogorgia kinoshitae Kukenthal, 1913	x	x	127 - 464	NMFS, Etnoyer and Morgan (2003)
	Calyptrophora sp.		x		Carey et al. (1990)
	Narella sp. cf. *bowersi* Nutting, 1908		x		Carey et al. (1990)
	Parastenella doederleini Wright and Studer, 1889	x	x		Etnoyer and Morgan (2003)
	Parastenella sp.		x		Etnoyer and Morgan (2003)
	Plumarella longispina Kinoshita, 1908		x		Etnoyer and Morgan (2003)
	Primnoa pacifica Kinoshita, 1907	x	x		OCNMS, unpublished data

Higher Taxon	Coral Taxa	San Diego	Oregon	Depth (m)	Source
	Thouarella sp.		x		Etnoyer and Morgan (2003)
Order Alcyonacea					
Family Alcyoniidae	*Alcyonium rudyi* Verseveldt and van Ofwegen, 1992		x		Cairns et al. (2002)
	Anthomastus ritteri Nutting, 1909	x	x	293 - 972	NMFS
Family Clavulariidae	*Cryptophyton goddarti* Williams, 2000		x		Cairns et al. (2002)
	Clavularia sp. A		x		Austin (1985)
	Clavularia sp. H	x			Hochberg (1978), Montagne and Cadien (2001)
	Telestula ambigua Nutting, 1909		x		Austin (1985)
	Telesto sp.	x			Montagne and Cadien (2001)
Family Nephtheidae	*Gersemia rubiformis* (Ehrenberg, 1834)		x		Austin (1985)
Order Pennatulacea					
Suborder Sessiliflorae					
Family Renillidae	*Renilla koellikeri* Pfeffer, 1886	x			Montagne and Cadien (2001)
	Renilla reniformis (Pallas, 1766)	x		intertidal	Berntson et al. (2001)
Family Kophobelemnidae	*Kophobelemnon affine* Studer, 1894		x		Hochberg and Ljubenkov (1998)
	Kophobelemnon biflorum Pasternak, 1960		x		Austin (1985)
	Kophobelemnon hispidum Nutting, 1912		x		Austin (1985)
Family Anthoptilidae	*Anthoptilum grandiflorum* (Verrill, 1879)	x	x	103 - 1543	Hochberg and Ljubenkov (1998), NMFS
	Anthoptilum murrayi Kolliker, 1880	x	x	516 - 1083	NMFS
Family Funiculinidae	*Funiculina parkeri* Kukenthal, 1913	x	x		Hochberg and Ljubenkov (1998)
Family Protoptilidae	*Distichoptilum gracile* Verrill, 1882		x		Hochberg and Ljubenkov (1998)
	Helicoptilum rigidum Nutting, 1912		x		Austin (1985)
Family Stachyptilidae	*Stachyptilum superbum* Studer, 1894	x	x		Montagne and Cadien (2001)
Family Scleroptilidae	*Scleroptilum* sp.		x		Austin (1985)
Family Umbellulidae	*Umbellula lindahli* Kolliker, 1874	x			Austin (1985)
	Umbellula magniflora		x		Hochberg and Ljubenkov (1998)
Family Halipteridae	*Halipteris californica* Moroff, 1902	x			Hochberg and Ljubenkov (1998)

Higher Taxon	Coral Taxa	San Diego	Oregon	Depth (m)	Source
	Halipteris sp.		x		
Suborder Subselliflorae					
Family Virgularidae	*Acanthoptilum album* Nutting, 1909	x	x		Hochberg and Ljubenkov (1998)
	Acanthoptilum gracile (Gabb, 1863)		x		Hochberg and Ljubenkov (1998)
	Stylatula elongata (Gabb, 1862)	x	x		Hochberg and Ljubenkov (1998)
	Stylatula gracilis Verrill, 1864	x	x	64 - 1243	Hochberg and Ljubenkov (1998), NMFS
	Stylatula sp. A	x			Ljubenkov (1991), Montagne and Cadien (2001)
	Virgularia agassizii Studer, 1894	x			Montagne and Cadien (2001)
	Virgularia californica Pfeffer, 1886	x			Montagne and Cadien (2001)
	Virgularia cystiferum (Nutting, 1909)	x	x		Austin (1985)
	Virgularia sp. cf *glacialis* Kolliker, 1870		x		Austin (1985)
Family Pennatulidae	*Pennatula californica* Kukenthal, 1913	x	x	465 - 991	Hochberg and Ljubenkov (1998), NMFS
	Ptilosarcus gurneyi (Gray, 1860)	x	x	11 - 922	Hochberg and Ljubenkov (1998), NMFS
	Ptilosarcus undulatus Verrill, 1865		x		Cairns et al. (2002)
Class Hydrozoa					
Order Anthoathecatae					
Suborder Filifera					
Family Stylasteridae	*Errinopora pourtalesii* (Dall, 1884)		x	49-183	Fisher (1938), Alberto Lindner, pers. comm.
	Stylantheca petrograpta (Fisher, 1938)		x	intertidal	Fisher (1938), Alberto Lindner, pers. comm.
	Stylantheca porphyra Fisher, 1931		x	intertidal	Fisher (1938), Alberto Lindner, pers. comm., Etnoyer and Morgan (2003)
	Stylaster californicus (Verrill, 1866)	x	x	35-90	Fisher (1938), Alberto Lindner, pers. comm., Etnoyer and Morgan (2003)
	Stylaster venustus (Verrill, 1868)		x	49-84	Fisher (1938), Alberto Lindner, pers. comm., Etnoyer and Morgan (2003)

STATE OF DEEP CORAL ECOSYSTEMS IN THE U.S. PACIFIC ISLANDS REGION: HAWAII AND THE U.S. PACIFIC TERRITORIES

Frank A. Parrish[1] and Amy R. Baco[2]

I. INTRODUCTION

The U.S. Pacific Islands Region consists of more than 50 oceanic islands, including two archipelagos (Hawaii and Mariana Islands), parts of four other archipelagos (Samoa, Line Islands, Phoenix Islands, and Marshall Islands), and numerous seamounts in proximity to each of these groups. These islands include the State of Hawaii, the Commonwealth of the Northern Mariana Islands (CNMI), and the territories of Guam and American Samoa, as well as nine sovereign Federal territories—Midway Atoll, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Howland Island, Baker Island, Rose Atoll, and Wake Island). This area also encompasses the Pacific Island States in free association with the United States (former U.S. trust territories also known as the Freely Associated States) including the Republic of Palau, the Federated States of Micronesia (Chuuk, Pohnpei, Kosrae, and Yap), and the Republic of the Marshall Islands. This region includes some of the most remote, unpopulated islands in the Pacific, as well as many densely populated islands, and it extends from the South Pacific (e.g., American Samoa; 14º S latitude) to the North Pacific (Kure Atoll 28º N latitude) (Figure 4.1). The punctuated habitat of the Pacific Region distinguishes deepwater coral communities biogeographically and ecologically from other areas in the United States. Because of the isolated nature of these islands (especially Hawaii and the Northwestern Hawaiian Islands), they possess some of the highest levels of marine endemism recorded anywhere on earth.

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While trace coral samples from anecdotal dredging and bycatch suggest a wide distribution of deep corals throughout the Pacific, the only detailed assessment of deep corals within the U.S. waters of the Pacific has been in the Hawaiian Archipelago. Antipatharians were first reported from Hawaiian waters more than 75 years ago (Verrill 1928). The earliest descriptions of deep octocorals in Hawaii are recorded by Dana (1846), with Nutting (1908) reporting 68 species. Other significant contributions to the species lists of this region include Muzik (1979) and Grigg and Bayer (1976) for octocorals, as well as Vaughan (1907) and Cairns (1984, 2006) for scleractinians. Wells (1954) provides data on the Marshall Islands. Pacific deep coral research has expanded greatly over the last four decades, primarily as a result of the establishment of commercial fisheries for black, pink, and gold coral off the main Hawaiian Islands, and subsequent development of fishery management plans for these resources by the State of Hawaii and the Western Pacific Fishery Management Council. Deep corals are harvested as raw material for the jewelry trade. The coral supports a portion of a $70 million Hawaii-based industry that employs roughly 650 people in its manufacturing facility and 50 retail stores (Carl Marsh—Maui Divers pers. comm.)

Commercial beds of black coral were first discovered at a depth of 30-75 m off Lahaina, Maui in 1958. Some of the earliest ecological work on black corals was carried out in the 1960s in the channel waters off Maui using SCUBA (Grigg 1965). The Maui black coral bed has remained the focus of coral harvesters throughout the fishery's history and has been periodically resurveyed over the last 40 years. These studies have provided the longest data sets available worldwide on the status and trends of black coral populations and the effects of the commercial fishery and other natural and anthropogenic stressors. In the mid 1960s, isolated patches of pink (*Corallium* spp.), gold (*Gerardia* sp.) and bamboo (*Lepidisis* sp., *Acanella* sp.) corals

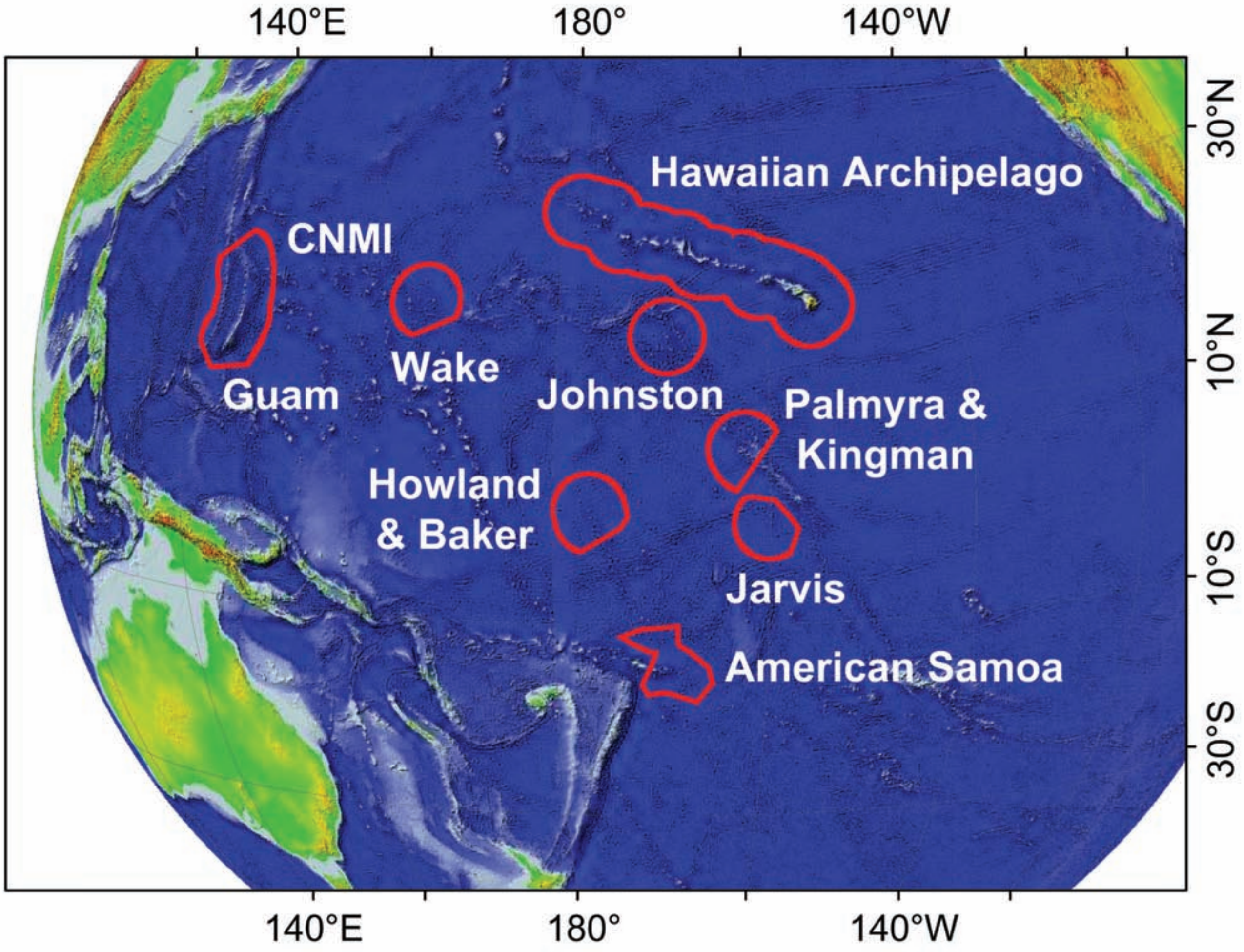

Figure 4.1. Map of the Pacific Basin showing U.S. islands and their Exclusive Economic Zone that comprise the Pacific Islands Region for the National Marine Fisheries Service.

were identified at 300–500 m depths north of Midway Island (Milwaukee Banks) and off Oahu (Makapuu Bed) (Grigg 1993). A long-term deep coral research program focused on precious corals began at the University of Hawaii in 1970. Many of the earliest surveys of precious coral beds used tangle net dredges and other nonselective gear. A key advancement in Hawaii's deep coral research infrastructure was access to the two-person submersible *Deep Star 2* from General Dynamics. Aside from periodic research (Grigg 1993) the sub was leased to commercially harvest coral for the fishery between 1974 and 1979. In 1980 the submersible was renamed the *Makalii* and became the centerpiece of the newly formed Hawaii Undersea Research Laboratory (HURL), an established node of NOAA's Undersea Research Program (NURP). The facility has since expanded, replacing the *Makalii* with two, deep-diving 3-person submersibles (*Pisces IV* and *Pisces V*) and a dedicated support vessel equipped with a multibeam bottom mapper and a remotely operated vehicle (*RCV-150*) (Chave and Malahoff 1998). This new infrastructure expanded the focus of coral research and increased participation by more researchers.

This chapter provides a summary of what is known about deep corals within the Pacific Islands Region. In keeping with the intent of this national report, the chapter will mostly focus on corals deeper than 50 m. However, shallower black corals will be included. Most of the information available on black corals, precious corals, and other deep corals are from the Hawaiian Archipelago, where most of the surveys have been conducted. Studies have focused on the taxonomic and genetic composition of the region's coral community, ecological relationships between corals and other organisms, and on the distribution and dynamics of deep corals. Much of this work is focused on the coral taxa that are targets for the commercial fishery. Also discussed are the measures that have been employed to protect deep coral ecosystems and to manage the commercial fishery.

II. GEOLOGICAL SETTING

The U.S. Pacific Islands lack the shelf area that typically defines the deep-sea benthic habitats of the continental United States. Instead, the submerged slopes of volcanic pinnacles that rise steeply from abyssal depths of 4–7 km provide the hard substratum that deep corals colonize. The region has endured a long history of plate drift, subsidence, and sea level rise, and many of the volcanic islands have drowned creating numerous submerged banks and seamounts. A striking feature of the Pacific Basin is the linear nature of the island chains and seamounts. They are aligned in a north-northwesterly direction, a consequence of the northwesterly drift of the Pacific plate over stationary volcanic hotspots (Kennett 1982). The resulting islands and seamounts are progressively older in proportion to distance from a hotspot. For example, the island of Hawaii lies above the mantle plume and is the only island in the Hawaiian Archipelago that is volcanically active. To the northwest, volcanism on Oahu ceased about three million years ago; Kauai about five million years ago; and Midway Island about 27 million years ago (Grigg 1988a). This geologic process defines the Pacific plate and, as a result, the Pacific Islands region has some of the youngest (main Hawaiian Islands) and oldest (Line Islands) volcanic archipelagos in the world.

III. OCEANOGRAPHIC SETTING

The Pacific is composed of two large gyres, the northern and southern central gyres. In the South Pacific, southeast trade winds drive the South Equatorial Current westerly between 15° S and 3° N latitude. Within the South Equatorial Current is the Cromwell Current, or Pacific Equatorial Undercurrent. This current exists at depths of 70–200 m, and is approximately 450 km wide and flows with velocities of up to 5 km h^{-1} for a distance of up to 13,000 km in the opposite direction of the South Equatorial Current (Tchernia 1980; Thurman 1981). In the North Pacific, the North Equatorial Current flows westward at 1 km h^{-1} between 8° and 20° N latitude. The Equatorial Counter Current is located between the North Equatorial Current and the South Equatorial Current and travels eastward at slightly more than 2 km h^{-1} (Thurman 1981). The boundaries of these water masses overlap and contribute to long-distance dispersal of pelagic larvae, particularly in the western Pacific. The northern Hawaiian seamounts fall in the northern portions of the north gyre; Hawaii, Wake and Johnston are in the center of the North Pacific gyre; Kingman and Palmyra are in the equatorial/eastern Pacific; Jarvis, Howland, and Baker are in the equatorial system; American Samoa is in the equatorial portion of the southern gyre; and the Mariana Islands are affected by the north central gyre, the equatorial systems, and the Kuroshio current from Asia.

While deep water masses originate from surface currents, no deep water masses form in the Pacific Basin. Deep water migrates in from the Atlantic via the southern hemisphere with a uniform temperature and salinity below about 2000 m (Knauss 1996). The deep water flows northward at depths below 2500 m and southward above 2500 m. Seamounts, pinnacles, and other structures obstruct current flow and can generate eddies of varying intensity, depending on the current velocity, depth or height of the seamount, slope of the side, and strength of the seawater stratification. Both cold and warm water eddies are formed as a result of a seamount obstructing current flow in the deep ocean. Typically, anticyclonic (cold water) eddies are formed above the seamount and remain tightly associated with the top of the seamount, while the cyclonic (warm water) eddy is formed downstream behind the seamount (Kamenkovich et al. 1986). Deep corals are thought to benefit from the flow acceleration, larval retention, and high nutrient waters from deep upwelling caused by the presence of the seamount and the generated eddies (Genin et al. 1986; Mullineaux and Mills 1997; Coutis and Middleton 2002).

Oxygen in the deep water of the Pacific has been depleted to very low levels as a result of the length of time it takes for water to move into and across the Pacific Basin. Having aged thousands of years, oxygen averages 0.5–4.5 ml l^{-1} versus the significantly higher Atlantic average of 3.0–6.5 ml l^{-1} (Thurman 1981). The effect of low oxygen levels on deep corals is poorly documented; however, Wishner et al. (1990) attributed patterns in the abundance and distribution of sponges, sea pens, and other benthic organisms to depth-specific patterns in oxygen levels.

IV. STRUCTURE AND HABITAT-FORMING DEEP CORALS

Most of the major deep coral groups are known to exist in the U.S. Pacific region. However, most species have been identified only around the Hawaiian Archipelago largely because deep waters around other U.S Pacific Islands have not yet been explored. Published records of deep corals from the Hawaiian Archipelago include more than 137 species of gorgonian octocorals and 63 species of azooxanthellate scleractinians, with 21% of the scleractinians thought to be endemic to Hawaii (Cairns 2006, See chapter appendix). A 2003 cruise in the Northwestern Hawaiian Islands (A. Baco, unpublished data) identified eight new species of octocorals, two new genera and several new species of antipatharians, three new stylasterid species (Cairns 2005), and 1 new zoanthid species. In addition, a 2004 main Hawaiian Islands cruise collected at least three new species of octocorals, two new species of

Table 4.1 Structure-forming attributes of deep corals in Hawaii.

Taxa	Reef-Building	Abundance	Maximum Colony Size	Morphology	Associations with Other Structure-Forming Invertebrates	Colony Spatial Dispersion	Overall Rating of Structural Importance
Enallopsammia rostrata	No	Medium	Medium	Branching	Many	Clumped	Medium
Other scleractinians	No	Low	Small	Non-Branching	Many	Solitary	Low
Gerardia sp.	No	High	Large	Branching	Many	Clumped	High
Shallower antipatharians	No	Low	Large	Branching	Few	Clumped	High
Other octocorals and antipatharians in deeper water	No	High	Med	Branching	Many	Clumped	High
Other octocorals and antipatharians in precious coral beds	No	Medium	Medium -Low	Branching	Many	Clumped	High
Corallium secundum	No	High	Medium	Branching	Many	Clumped	Medium
Corallium laauense	No	High	Medium	Branching	Many	Clumped	Medium
Isidids in deeper water	No	High	Med	Branching	Many	Clumped	Medium

Table Key	
Attribute	**Measure**
Reef-Building	Yes/No
Relative Abundance	Low/ Medium/ High
Size (width or height)	Small (<30cm)/ Medium (30cm-1m)/ Large (>1m)
Morphology	Branching/ Non-branching
Associations	None/ Few (1-2)/ Many (>2)
Spatial Dispersion	Solitary/ Clumped
Overall Rating	Low/ Medium/ High

antipatharians, and provided range extensions for several genera and species of corals that were not previously known from Hawaii. Thus, although an extensive species list exists for the Hawaiian Archipelago, the high rate of discovery of new species and new records implies the Archipelago is also largely undersampled.

In general, the deep corals in the Pacific Islands do not form the extensive reef structures observed in the Atlantic and South Pacific. Instead, corals grow attached directly to the exposed fossil carbonate, basalt or manganese substratum. Octocorals and antipatharians have been found to grow in high densities at numerous sites, particularly on summit areas of seamounts or other topographic highs, where they often form extensive coral gardens or "beds" with abundant associated invertebrates. The coral taxa listed in this chapter are those that present a conspicuous relief profile that could serve as a source of habitat (Table 4.1). At death, these taxa decay from physical and bioerosion forces until they detach from the substratum and are swept away. Cemented reefs from accumulated dead material have not been observed.

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

Enallopsammia rostrata is an arborescent scleractinian coral in the Family Dendrophylliidae. The full depth range for this species is listed as 229–2165 m in Cairns (1984), but it has been observed in Hawaii primarily at depths of 500–600 m. In some areas it forms bushy colonies, with dead coral accumulating near the base of the colony much like that observed among *Lophelia* reefs in the Atlantic. Further exploration and characterization of this species is needed to determine its abundance throughout the region and its potential role in forming habitat.

Madrepora kauaiensis and *M. oculata* also occur in Hawaii and have the potential to form reef structures, however, little is known of their abundance or distribution in the Archipelago. Besides these examples, scleractinians that have been observed are primarily solitary cup corals. They can occur in abundance, e.g., on Cross Seamount (A. Baco pers. obs), but many species are small and not observable with a submersible, preventing a true determination of their distribution. A complete species list (to date) for Hawaii can be found in Cairns (2006) and is also included in the Appendix to this chapter.

b. *Black corals* (Class Anthozoa, Order Antipatharia)

Fourteen genera of black corals are reported from the Hawaii-Pacific region with species found in both shallow and deep habitats. The shallowest genera (*Cirripathes* spp. and *Antipathes* spp.) prefer shaded or low light areas and can occur underneath ledges and in caves in shallow water (e.g., *Cirrhipathes anguina* can occur in 4 m depth) where surge is minimal, or in the open on steep walls at deeper depths. A*ntipathes* spp. appears to settle predominantly in depressions, cracks or other rugged features along steep ledges, with few colonies found on smooth basaltic substratum (Grigg 1965). Shallower antipatharians in Hawaii also appear to prefer substrates that are encrusted with calcium carbonate from coralline algae, bryozoans, and corals. The highest densities are found on hard sloping substratum, in areas with 0.5–2 knot currents (Grigg 1965). The best studied black corals are the commercially harvested species *Antipathes dichotoma* and *Antipathes grandis*. Recent taxonomic work (D. Opresko pers. comm.) on the Hawaiian *A. dichotoma* suggests it is a new species and is currently being referred to as *Antipathes* cf. *curvata*. The *A.* cf. *curvata* and *A. grandis* exhibit similar growth rates (6.42 cm yr^{-1} and 6.12 cm yr^{-1}, respectively) and reach reproductive maturity at ages 12–13. Fertilization takes place externally in the water column, and light and temperature influence larval settlement patterns. The larvae of *A.* cf. *curvata* and *A. grandis* are negatively phototactic, and the lower depth limit coincides with the top of the thermocline (~ 100 m) in the main Hawaiian Islands (Grigg 1993).

Much less is known about deeper genera of black corals. They have similar morphologies to the shallower corals, including colonies shaped as whip-like filaments (*Stichopathes* spp.) and as branching, sometimes "feathery" colonies (*Myriopathes, Bathypathes* spp., *Stauropathes* and *Leiopathes*). However, the life history of these deeper genera is likely to be much different than their shallower relatives. Radiometric dating of *A.* cf. *cruvata* and *Leiopathes* indicates the deeper *Leiopathes* genera grow 10 to 70 times slower than the shallower *A.* cf. *curvata* (Roark et al. 2006).

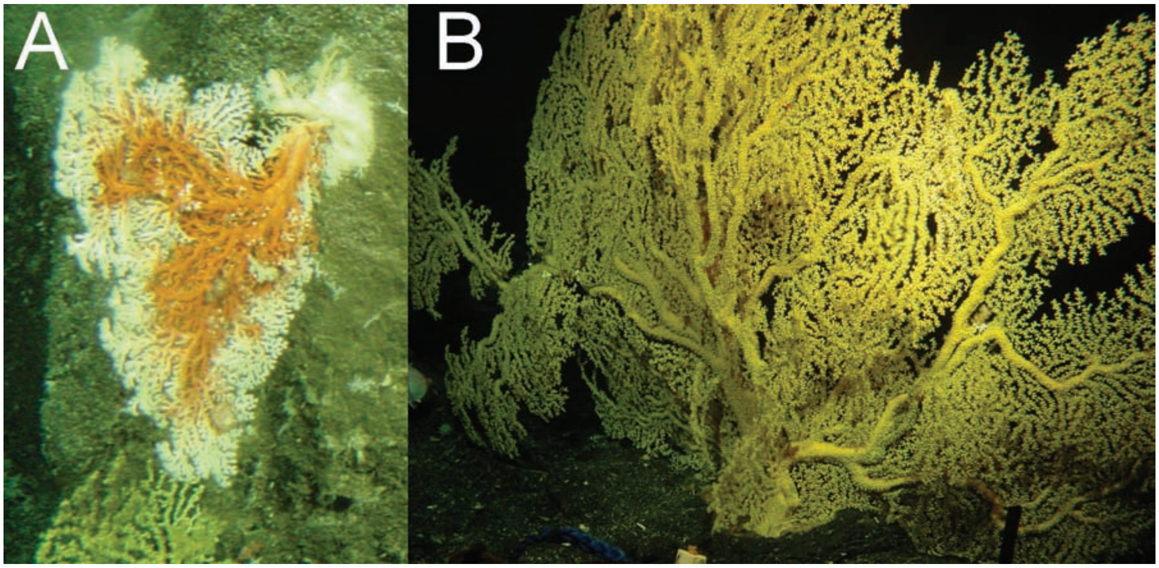

Figure 4.2. Photos of the two primary Genera that comprise the Hawaiian precious coral fishery A—*Corallium* sp. and B—*Gerardia* sp. Photo credit F. Parrish, NOAA Fisheries.

c. *Gold coral* (Class Anthozoa, Order Zoanthidea)

No species of zoanthid has yet been described from deep water in Hawaii although taxonomically, at least six species have been observed and,ollected (Baco, unpublished data). The gold coral, *Gerardia* sp., is probably the most common and certainly the largest of these species. It has an arborescent morphology similar to gorgonians, and colonies have been observed as tall as 2–3 m in height (Figure 4.2 B). *Gerardia* sp. is widely distributed throughout the Hawaiian Archipelago and into the Emperor Seamount Chain at depths of 350–600 m.

Zoanthids in Hawaii have been observed to colonize other living coral species as well as hard bottoms. In the case of *Gerardia* sp., the zoanthids may eventually replace the host colony completely. It is not known if *Gerardia* sp. can outcompete the living tissue of the host or if it opportunistically colonizes and spreads after a portion of the host coral has been decorticated by predatory urchins or some other cause. The life span of *Gerardia* sp. is uncertain. Counts of growth bands assumed to be annual in periodicity have provided an estimated lifespan of around 40 years (Grigg 2002). Recent radiometric work on the Hawaiian species has estimated the life span of gold coral samples between 450 and 2700 years (Roark et al. 2006), which is consistent with findings from radiometric aging on *Gerardia* sp. in the Atlantic (Druffel et al. 1995).

Gold coral was one of the few corals seen during the 2005 Line Island surveys and it was present at Jarvis, Palymra, and Kingman. However, the colonies were sparse, with no patches large enough to be called a “bed.” All colonies were infested with other unidentified zoanthids. Surveys at the base of the cliffs below the spot where the individual gold colonies were attached found no accumulation of fallen colonies, suggesting gold coral has always been in low abundance in the region (Frank Parrish pers. obs.).

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

Gorgonian octocorals are by far the most abundant and diverse corals in the Hawaiian Archipelago. Two species, *Corallium laauense* (red coral; formely identified as *Corallium regale*) and *Corallium secundum* (pink coral) are known to occur at depths of 350–600 m on islands and seamounts throughout the Hawaiian Archipelago (Grigg 1974, 1993; Baco, unpublished data) and into the Emperor Seamount Chain (Bayer 1956). Growing to more that 30 cm in height the *Corallium* spp. occur in a variety of red/pink color shades, and the height and shape of the colony’s “fan” can vary considerably (Figure 4.2 A). They are often found in large beds and usually support a high diversity of invertebrates with an abundance of other octocorals, zoanthids, and sometimes scleractinians co-occuring in the beds. *C. secundum* and *C. laauense* are gonochoristic (Grigg 1993; Waller and Baco in press) and are estimated to reach reproductive maturity at 12–13 years (Grigg 1993). These species are relatively long lived, with some of the oldest colonies observed within Makapuu Bed about 0.7 m in height and approximately 80 years old (Grigg 1988b, Roark 2006). Populations of *C. secundum* appear to be recruitment limited, although in favorable environments (e.g., Makapuu Bed) populations are relatively stable, suggesting that recruitment and mortality are in a steady state (Grigg 1993).

More than 130 other species of octocorals are known from the Archipelago and they represent a diverse array of families and genera. Most abundant are the Families Coralliidae, Isididae, Primnoidae, Plexauridae, Chrysogorgiidae and Acanthogorgiidae. To our knowledge, besides the species discussed above, there isn't any information on the biology and ecology of these groups in this region. Further discussion of their depth distributions are in the following sections and a complete species list (to date) is included in the Appendix to this chapter.

e. *True soft corals* (Class Anthozoa, Order Alcyonacea)

The Alcyonacea are represented in this region by only 12 species in three families. Of these, the genus *Anthomastus* is the most widely distributed. It is often observed in precious coral beds in patches with large number of small individuals surrounding a larger individual (A. Baco pers. obs.). The bright purple *Clavularia grandiflora* has been observed growing on *Gerardia* at a number of sites throughout the Archipelago (A. Baco pers. obs.)

Like the gorgonians, little else is known about the biology and ecology of these species in this region. A complete species list (to date) is included in the Appendix to this chapter.

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

Pennatulaceans seen in Hawaii tend to be more abundant in areas high in sediment, although *Kophobelemnon* sp. has occasionally been observed on adjacent hard bottoms near the Cross Seamount deep coral bed. Near the Keahole deep coral bed on the island of Hawaii, a single species (as yet unidentified) occurs in high abundance in patches of sediment at depths of about 400 m (A. Baco pers. obs.). Again, little else is known about the biology and ecology of these species in this region. A complete species list (to date) is included in the Appendix to this chapter.

g. *Stylasterids* (Class Hydrozoa, Order Anthoathecatae)

Four species of stylaserids are present in Hawaii, but they are distributed very patchily throughout the Archipelago. An extreme example is *Disticophora anceps*. It has a very wide depth range but has only been found on the northwest slope of Laysan Island in densities of several colonies per square meter in some areas (Cairns 2005; A. Baco unpublished data). Again, little else is known about the biology and ecology of this group in this region.

Hawaiian stylasterids are discussed in Cairns (2005) and a complete species list (to date) is included in the Appendix to this chapter.

V. SPATIAL DISTRIBUTION OF CORAL SPECIES AND HABITAT

General distribution

Our knowledge of the spatial distribution of deep corals in the U.S. Insular Pacific is limited to Hawaii. Even in Hawaii, very little of the deep sea has been explored and every research expedition is yielding large numbers of new species. Until 2003, the majority of studies in Hawaii came from sparse trawl data or had concentrated on the harvested black, gold, and pink corals. Often referred to as "precious corals," these are the primary deep coral taxa harvested for the jewelry trade. Most of these are found between depths of 300 and 500 m and have been collected by dredge or submersible. Often, black coral (*Antipathes* spp.) is distinguished from the rest of the precious corals because the *Antipathes* taxa that are used for jewelry occur much shallower (<100 m) and are harvested by scuba divers. Beside precious corals, many other taxa of deep corals have not been studied because they were not one of the management unit species of the precious coral fishery. In 2003 and 2004, the *Pisces* submersibles were used for the first studies of non-precious corals, thus extending the exploration of corals well below previously surveyed depths. In 2005, the first surveys conducted outside of Hawaii using the *Pisces* submersibles were at Rose Atoll and the U.S Line Islands (Jarvis, Palmyra, and Kingman).

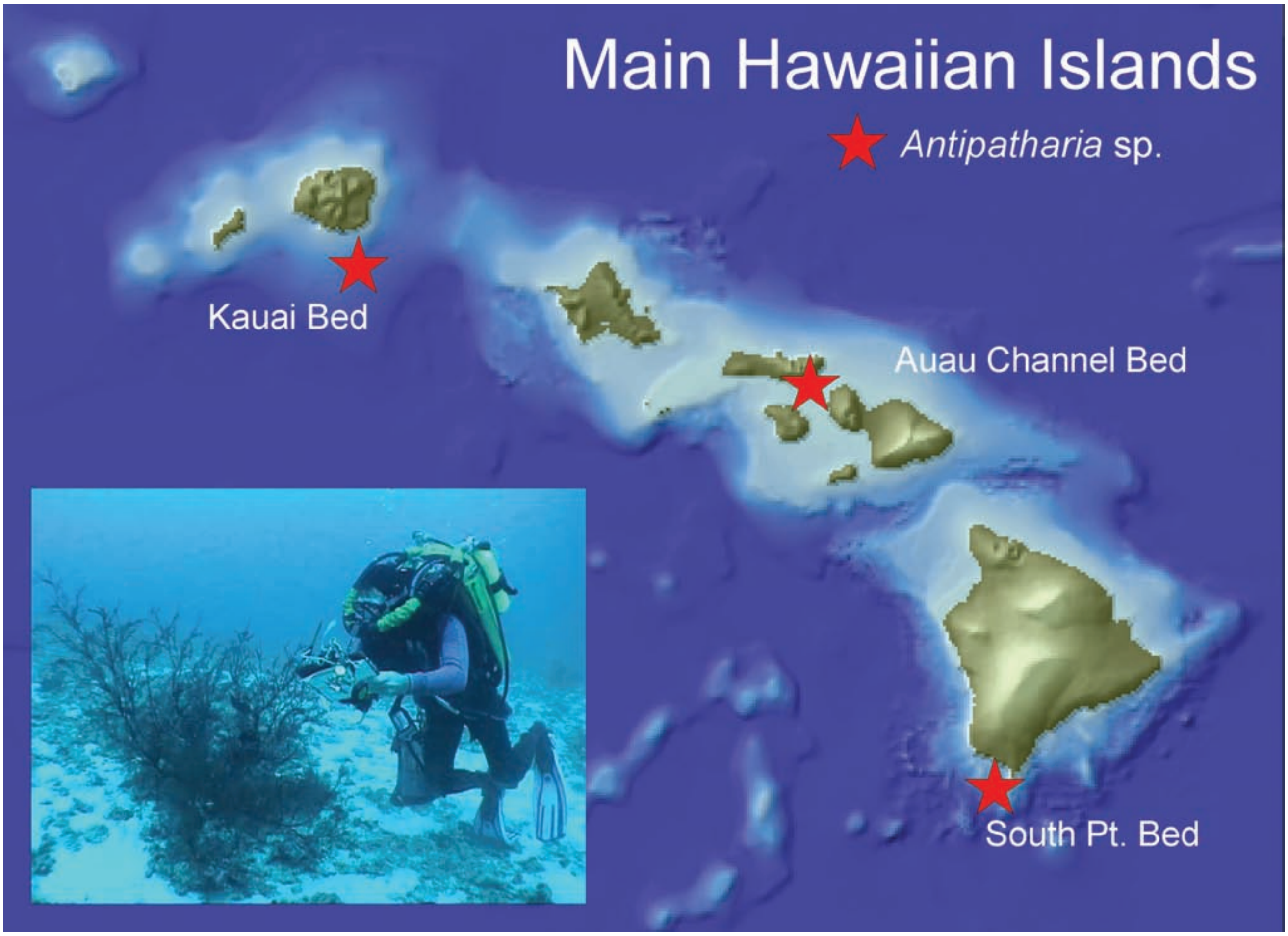

Figure 4.3. Topographic map of the main Hawaiian Islands with the three known black coral beds marked. Inset shows a diver conducting a coral survey. Map creidt: F. Parrish, NOAA Fisheries.

The distribution of deep corals in the rest of the U.S. Pacific is unknown.

Depth clearly influences the distribution of different coral taxa and certainly there is patchiness associated with the presence of premium substrate and environmental conditions (flow, particulate load, etc.). The environmental suitability for colonization and growth is likely to differ among coral taxa. For example, *Corallium secundum* appears to grow in large numbers in areas of high flow over carbonate pavement; *Corallium laauense* grows in an intermediate relief of outcrops; and *Gerardia* sp. grows in high relief areas on pinnacles, walls, and cliffs (Parrish in press). These habitat differences may reflect preferred flow regimes for the different corals (e.g., laminar flow for *C. secundum*, alternating flow for *Gerardia* sp.).

Black coral beds

Black coral beds are found off the main Hawaiian Islands at depths of about 30–110 m. The largest bed covers an estimated area of 1.7 km^2 and lies in the middle of the Auau Channel, between Maui and Lanai, encrusting a drowned land bridge between the two islands at depths of 30-90 m (Grigg et al. 2002). A smaller black coral bed (0.4 km^2) is located off Kauai and another at the southern end of the island of Hawaii (Figure 4.3). The dominant species found in these locations are *Antipathes* cf. *curvata* (95% of the population) followed by *Antipathes grandis.* Grigg (1976) estimated a total standing crop of *A.* cf. *curvata* for the Auau Channel area, between 40 and 70 m, to be 166,000 kg or 84,000 colonies, while the bed at Kauai contained 40,000 kg. *Myriopathes ulex* is found in deeper locations (110–565 m) off the main Hawaiian Islands, along with other species of antipatharians absent from shallower depths (Devaney and Eldridge 1977) (see chapter appendix). Little commercially important black coral has been found in the Northwestern Hawaiian Islands (Grigg 1974), perhaps due to the shoaling of the thermocline towards the northwest end of the chain. Other species of black corals occur in the Northwestern Hawaiian Islands and include taxa such as *Cirripathes*, *Stichopathes*, *Stauropathes*, *Bathypathes*, *Myriopathes ulex*, *Trissopathes, Umbellopathes, Dendropathes*, and *Leiopathes*.

Between Black and Precious Coral Beds

The depth zone between the black coral beds and the precious coral beds has had less study. Corals have been observed in this zone; for example, an abundance of octocorals occur at the Makapuu coral bed on the island of Oahu, shallower than the precious corals, but they have not been sufficiently sampled to comment on diversity or species composition.

Precious coral beds

Probably the most abundant of Hawaii's known deep corals are the precious corals, including octocorals *Corallium laauense* (red coral) and *Corallium secundum* (pink coral), and the zoanthid *Gerardia* sp. (gold coral). These species are known to occur in significant abundance in at least 16 locations in the Hawaiian Archipelago at depths of 350–600 m (Grigg 1974, 1993; Baco, unpublished data) and into the Emperor Seamount Chain (Bayer 1956). Within a given coral bed, the two primary genera (*Corallium* and *Gerardia*) are usually found, but the ratio of abundance can vary greatly (Parrish in press)(Figure 4.4). It is difficult to estimate the size of coral beds, so only relative differences in bed size (based on impressions of coral density and the area covered by the submersible track) were shown in Figure 4.4 to determine the size of pie diagrams. Most precious coral sites also have a number of other noncommercial taxa; these include various octocorals (e.g., *Callogorgia*, *Paracalyptrophora*, *Acanthogorgia*, *Lepidisis*, *Keratoisis*, *Isidella*, *Kereoides*, *Paragorgia,* and various paramuriceids) and antipatharians (e.g. *Leiopathes, Trissopathes,* and *Bathypathes*) (A. Baco, unpublished data).

Of the known coral beds, the Makapuu coral bed is the best studied and most diverse. It is located between 375 and 450 m depth in the channel between the islands of Oahu and Molokai. The bed comprises an area of about 3.6 km^2, with the most abundant coral *C. secundum*, at a mean density of 0.22 colonies per square meter between 365 and 400 m (Grigg 1988b). Other corals found at Makapuu include bamboo coral (*Lepidis olapa*, 0.041 colonies m^{-2}; *Acanella* spp., 0.001 colonies m^{-2}), gold coral (*Gerardia* sp., 0.0005 m^{-2}), as well as three genera of gorgonians

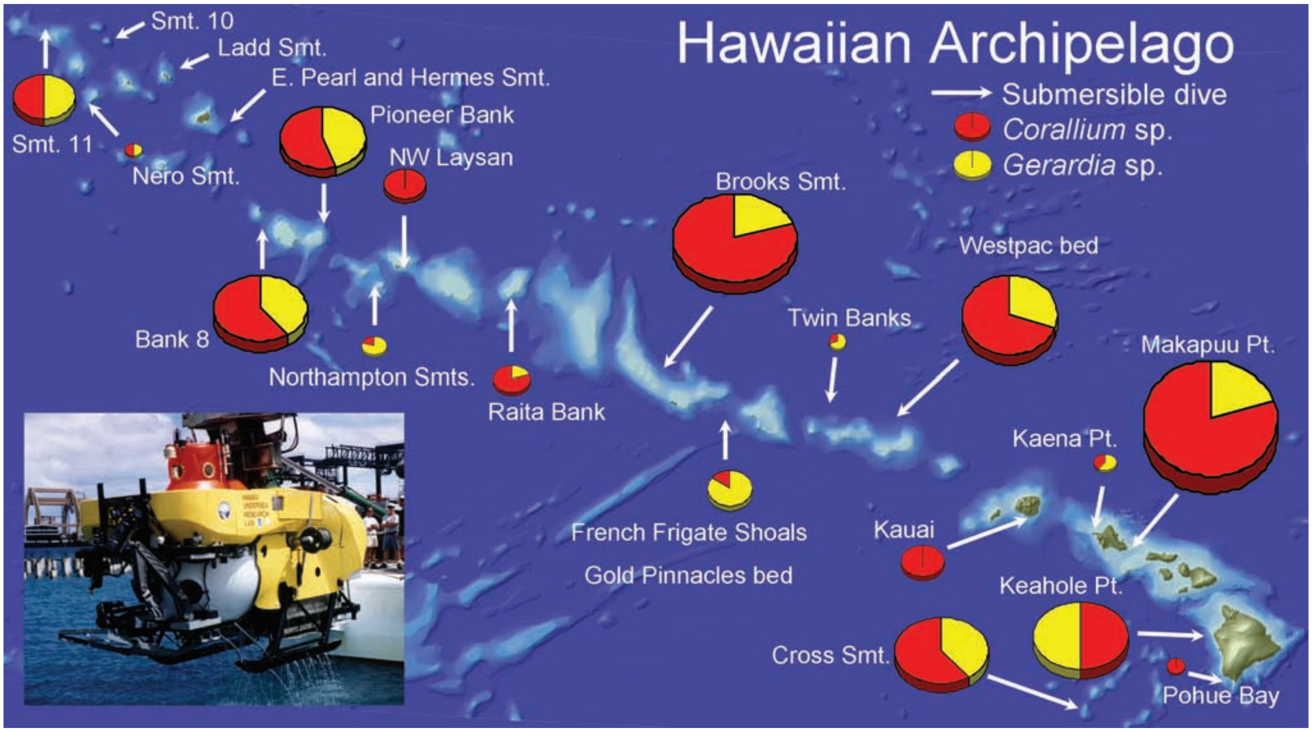

Figure 4.4. Topographic map of the Northwestern Hawaiian Islands with coral survey dive sites of the submersible Pisces V (inset). Pie charts represent the relative amount of coral among sites and the within-site fraction of the two primary precious coral genera. 3D map and Pisces photo credit: Hawaii Undersea Research Laboratory.

(*Narella* sp., *Psuedothesea* sp and *Callorgorgia gilberti*), a sea pen (*Stylatula* sp.), and black coral (*Leiopathes* n. sp.). Many taxa of no commercial interest are also present in or adjacent to the bed including *Enallopsammia rostrata, Thouarella hilgendorfi*, acanthogorgiids, *Paragorgia* sp., Paramuriceidae, *Trissopathes pseudotristicha* (antipatharian) and a number of undescribed octocorals.

Beyond Precious Coral Beds

Explorations have been conducted at only a few sites below precious coral depths; Pioneer Ridge, the small seamount southeast of Laysan Island, an unnamed seamount east of Necker Island, Cross Seamount, and Keahole Point. At these deeper depths in high current areas such as ridges and pinnacles, a fair amount of overlap appears to occur in species composition of both corals and sponges between sites. Although the number of observations is very limited, there appears to be a transition in species below about 600 m, from *Corallium*- and *Gerardia*-dominated communities, to a different suite of species. Many species of chrysogorgiids, primnoids, isidids, coralliids, and antipatharians begin to appear around this depth (A. Baco, unpublished data). Among the more common octocoral genera observed are: *Chrysogorgia, Metallogorgia, Iridigorgia, Narella, Calyptrophora, Candidella, Keratoisis, Isidella, Acanella, Corallium*, and *Paragorgia*, as well as the antipatharian genus Bathypathes. The depth distribution of many, but not all, of these species appears to continue below 1800 m (Baco, unpublished data).

V. SPECIES ASSOCIATIONS WITH DEEP CORAL COMMUNITIES

The harvesting of deep corals has prompted a number of studies focused on the species associations with deep coral communities. Nationally, most effects to coral-associated species come from trawling and dredging, which are banned in U.S. Pacific waters. The harvesting of precious corals is allowed using selective methodologies such as hand collection by scuba divers or using the manipulator of a submersible. Take of deep corals as a fishery target is a direct effect to the bottom habitat with uncertain ecological consequences. Studies have been conducted to address the NOAA mandate of essential fish habitat, protected species, and ecosystem concerns. These have historically been focused on fish and only recently have been expanded to include invertebrates.

Commercial fishery species

With the exception of the fishery that harvests precious corals, there is little evidence of a direct association between precious corals and other fishery targets. However, these evaluations have been limited to comparing the overlap in depth ranges and making infrequent underwater observations. Even less is known about the deep sea corals not targeted in the precious coral fishery, or any indirect ecological effects that any of these corals may contribute to commercial fishery stocks. Some of the shallow coral reef fish targeted by recreational fishers and the aquarium trade range into depths where black corals (antipatharians) can be found (30–100 m) (Moffitt et al. 1989; Parrish and Boland 2004; Boland and Parrish 2005). One of the commercially sought bottom fish *Aprion virescens* (grey snapper), also lives in this depth range but most of the commercial bottom

Figure 4.5. Two species of black coral trees *Antipathes grandis* (left) and *Antipathes. cf. curvata* (right). Photo credit F. Parrish, NOAA Fisheries.

fish reside at depths below antipatharians and above the precious corals (<300 m) (Uchida and Tagami 1984). The shallowest members of this group, such as *Pristipomoides filamentosus* (pink snapper), *Pristipomoides zonatus* (oblique-banded snapper), and *Epinephelus quernus* (Hawaiian grouper), have been seen in the vicinity of deeper black coral trees (Moffitt et al. 1989). Similarly, the deeper members including *Etelis carbunculus* (ruby snapper) and *Etelis coruscans* (flame snapper) have been seen among the shallower precious corals (Kelley et al. 2006). The groundfish, *Pseudopentaceros wheeleri* (armorhead) and *Beryx* sp. (alfonsino) occur throughout this depth range (250–350) but are more common on the seamounts at the northern end of the Hawaiian Archipelago (Uchida and Tagami 1984). There is no information on the degree of overlap of these fish with deep sea corals. *Heterocarpus* sp. (deep-water shrimp) has been seen among the precious corals but at densities consistent with other bottom relief types. *Heterocarpus* sp. is the focus of an intermittent main Hawaiian Island trap fishery that targets depths of 500 to 900 m (Moffitt and Parrish 1992) overlapping the lower limit of precious coral depths, but in the depth range of many other deep coral species.

Noncommercial species

Fish

Studies of fish associations with deep corals have focused almost exclusively on the inventory of fish taxa and appraisal of the obligate or facultative roles corals play in fish assemblages. The fish community of the Auau Channel black coral bed was recently surveyed (Boland and Parrish 2005) and 95% of the fish found in and around the black corals were known to commonly occur on shallower reefs where black corals do not grow. *Oxycirrhites typus* (the longnose hawkfish), was found exclusively within the black coral trees. Behavioral data indicated that although most of the reef fish routinely passed through the coral

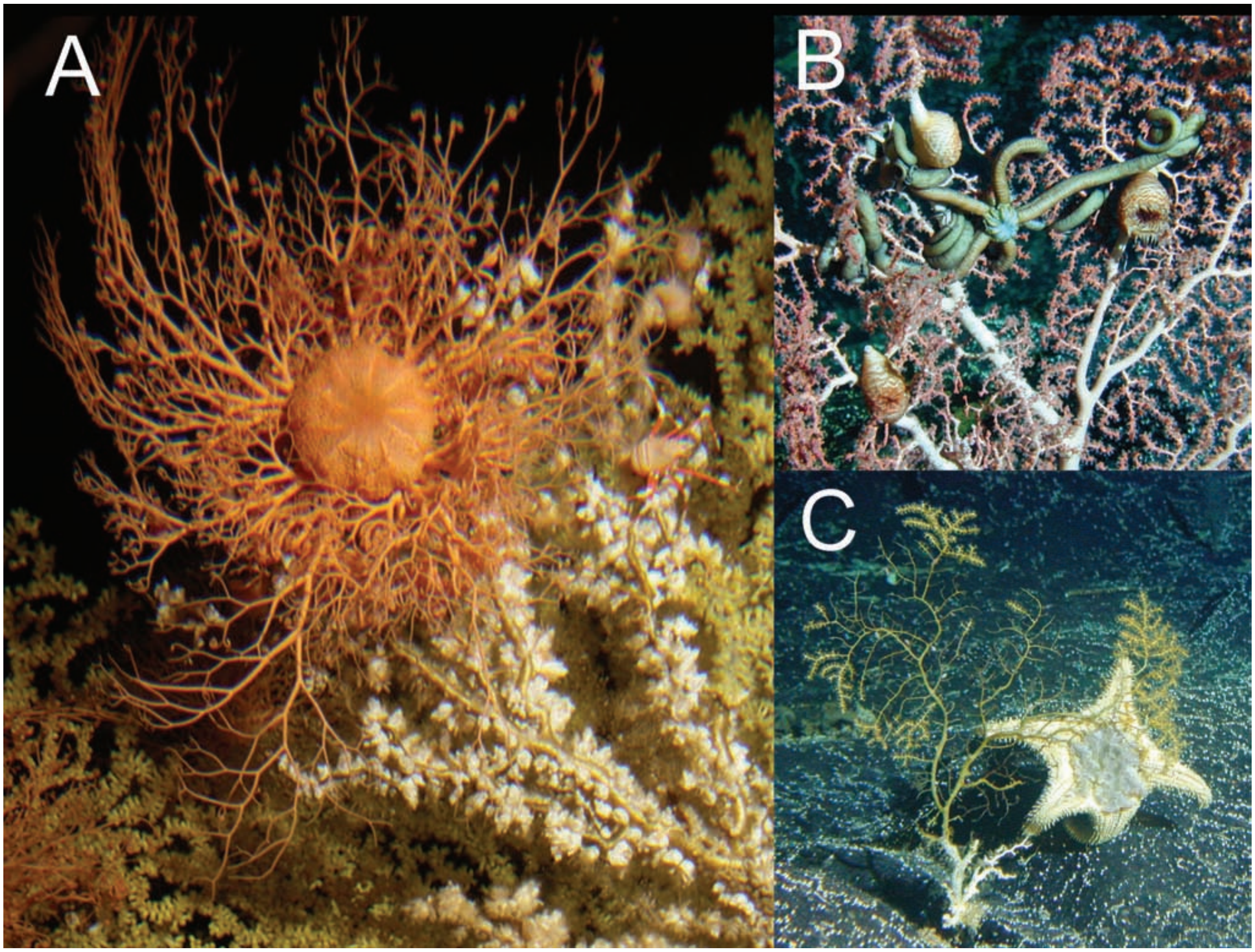

Figure 4.6. Examples of invertebrates found associated with deep corals (A-basket star, B-ophiuroid, C-asteroid. Photo credit A.Baco, WHOI.

branches, only four species reliably used the corals for cover when evading a threat (Figure 4.5). Although there is little or no known obligate relationship between fish and black coral, the coral colonies contribute to the fish community by enhancing the vertical aspects of the deep reef and perhaps improving the corridors for fish movement.

Most of the fish of the deep slope and subphotic depths are noncommercial species (Chave and Mundy 1994). The surveys of fish communities at deeper subphotic depths indicated few fish associations with precious corals (Parrish 2006). Many of the 42 fish taxa observed were seen to use *Gerardia* and *Corallium* spp. as shelter interchangeably with abiotic relief sources. Species richness of fish was not observed to differ between areas with corals and those without. Most fish taxa were observed in low numbers with only a couple of dominant species. Areas with corals often supported greater fish density, but statistical evaluations suggested that this was based on co-occurrence of fish and coral in areas of relief and high flow and not based on a dependency of fish on corals. Also, differences were not seen in the mean size of fish in or outside of the coral beds. Of the three commercial coral species, fish oriented mostly around *Gerardia* sp. probably because it is significantly taller than the two *Corallium* species. Classifying the fish into functional groups revealed "benthic hoverers" as the segment of the fish community that most frequently used *Gerardia* sp. as shelter.

Although use of corals by the fish appeared incidental, it is important to consider these studies were conducted in summer, during the day and focused exclusively on adult fish. It is unknown if the corals play some seasonal or diurnal role in the fish ecology or if juvenile stages rely on the coral colonies.

Invertebrates

There is a wide array of invertebrate species associated with deep corals. Black corals are

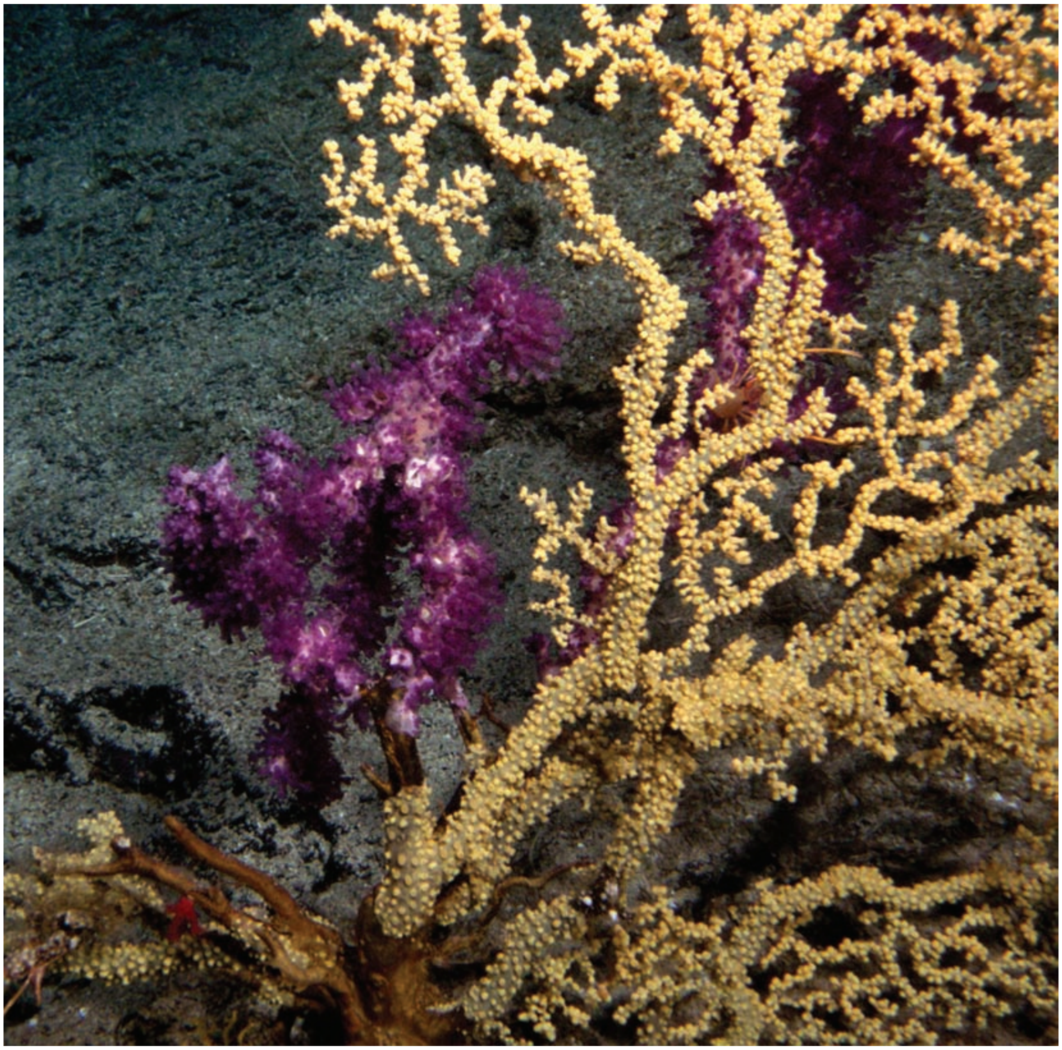

Figure 4.7. The purple octocoral *Clavularia grandiflora* growing on a *Gerardia* sp. colony.Photo credit A. Baco, WHOI.

known to be colonized by oysters, bryozoans, and shrimp (Hoover 1998). The most common invertebrates associated with the deeper precious corals include zoanthids, anemones, galathaeoid crabs, sponges, ophiuroids, and basket stars (Figure 4.6). *Gerardia* sp. is perhaps the best known coral that overgrows the skeletons of other coral species. Examination of *Gerardia* sp. skeletons and many submersible observations suggests it has an obligate need to start its colony over the skeleton of other corals. Bamboo corals seem to be the most frequent target, particularly *Isidella trichotoma*, but *Gerardia* has been observed growing on quite a number of species. Several other species of unidentified zoanthids also appear to prefer to grow on other corals, including *Gerardia* sp. At least one of these zoanthids was observed growing on basalt substrate as well as encrusting other corals (A. Baco pers. obs.). Octocorals also can grow on the skeletons of other coral species. The bright purple *Clavularia grandiflora* has been observed growing on *Gerardia* at a number of sites throughout the Archipelago (Figure 4.7). In all of these cases, it is not clear whether the overgrowing corals are actually killing or injuring the coral whose skeleton they are growing on, or if they have simply colonized a dead area of the skeleton.

Many coral colonies have a number of commensal invertebrates such as galathaeoid crabs, barnacles, sponges, anemones, polychaetes, crinoids, ophiuroids, and basket stars (Chave and Malahoff 1998; A. Baco and Shirley, unpublished data). Casual observations suggest some of these commensals may be specific to their host while others are more generalized. The relationships between the coral and the commensal, e.g., symbiotic, parasitic, obligate, facultative, etc., have not been determined in most cases and many of the commensal species have yet to be identified. One of the more notable commensal relationships is the general association of polychaetes with species in the genus *Corallium*. Each *Corallium* species appears to have its own species of polynoid polychaete. In *Corallium secundum* and *Corallium laauense*, these polychaetes can reach fairly high densities. The polychaetes live in tunnels under the coral soft tissue with the skeleton often growing over the polychaete tunnels. This relationship has also been observed in other corals such as *Candidella helminthophora*. A more generalized commensal is the unbranched basket star, *Asteroschema*. *Asteroschema* sp. has been observed in a number of different species of octocorals at a number of sites, but not on the surrounding substratum. Dead coral skeletons also appear to provide good recruitment habitat for many invertebrate species. Many types of sessile fauna have been observed as well as several types of young corals. In particular, young colonies of the red coral, *Corallium laauense* have been observed growing on dead skeletons of *Gerardia* sp.

Besides the galathaeoid crabs that inhabit the branches of coral colonies, a number of larger crabs are routinely encountered patrolling the bottom around deep corals (e.g., crabs in the families Homolidae, Parapaguridae).

Predation on deep corals by resident invertebrates also occurs. Seastars feed on coral colonies by everting their gut, leaving behind patches of bare coral skeleton. Cidarid urchins are also known to feed on deep corals and these urchins have been observed on deep corals in Hawaii. However, an absence of bare coral skeleton around the urchin's location suggests it is unlikely they are consuming the coral tissues (A. Baco, unpublished data). A single species of orange crinoid was observed in 2004 in very high densities at the Makapuu coral bed (A. Baco, unpublished data). Grigg 2002 comments on an abundant crinoid observed during night dives at this site. The crinoids now cover many octocoral colonies and anything else that sticks up more than a few millimeters off the bottom (A. Baco, unpublished data), suggesting their abundance has increased over Grigg's observations. Their origin and the reason for their recent increase in population density, as well as their potential for competing with corals for food, are unknown.

Monk seals

In the lower Northwestern Hawaiian Islands, the endangered Hawaiian monk seal has been documented to routinely visit deep corals as part of its foraging activities. However, there have been no reported interactions between monk seals and the precious coral harvesting in the main Hawaiian Islands. Telemetry and scatological analysis indicate seals prey on bottom-dwelling fish (Goodman-Lowe 1998; Parrish and Abernathy 2006; Longnecker et al. 2006). Video cameras fitted to seals in the

Table 4.2 Potential effects of fishing gears on deep coral habitat in Hawaii. Ratings detailed in table key. Tuna/Swordfish includes: Albacore, Bigeye tuna, Yellowfin Tuna, Skipjack Tuna, Swordfish, Striped Marlin, Pacific Blue Marlin, Black Marlin Sailfish, Shortbill spearfish, Wahoo, Dolphinfish, Opah, Pomfret, sharks. Deepwater shrimp include: two species of *Heterocarpus,* Snappers and Groupers include: Pink snapper, Flower snapper, Squirrelfish snapper, Hawaiian Grouper, Ruby-colored snapper, Blue-green snapperfish.

Gear Type	Current Fishery Use in Region	Potential Severity of Impact	Potential Extent of Impact from Fishing Gear	Current Geographic Extent of Use in Region	Overlap of use with coral habitat	Overall Rating of Gear Impact
Bottom Trawl	N/A	High	High	N/A	N/A	N/A
Mid-water Trawl	N/A	Low	Low	N/A	N/A	N/A
Dredge	N/A	High	Low	N/A	N/A	N/A
Bottom-set Longline	N/A	Med	Low	Low	N/A	N/A
Bottom-set Gillnet	N/A	Med	Med	N/A	N/A	N/A
Pelagic longline	Tuna/ swordfish	Low	Med	Med	Low	Low
Traps	Deepwater Shrimp	Med	Med	Low	Low	Low
Hook and line	Snappers/ groupers	Low	Low	High	Low	Low

Northwestern Hawaiian Islands have recorded seals commuting to beds of *Cirripathes* sp. whip corals (100 m) where they feed on eels. Satellite tags attached to seals indicated certain seals spent weeks of their foraging focused at specific subphotic locations where surveys with submarines have revealed red and gold corals (Parrish et al. 2002). More recent satellite tagging of seals at the northern extent of the Northwestern Hawaiian Islands shows similar feeding patterns to subphotic depths (Stewart et al. 2006). Monk seals have also been observed from the Pisces V submersible at more than 500 m while scientists were conducting coral surveys (A. Baco pers. obs.). The video of the encounter shows the seals briefly looking over the submersible and then using the light field from the sub to look into holes and cracks of the bottom.

VI. STRESSORS ON DEEP CORAL COMMUNITIES

Deep coral communities within the Pacific region may be affected by a number of natural and anthropogenic stressors. Natural mortality has been attributed to smothering by sediments and by bioerosion of the substrata at the attachment site, which leads to toppling of colonies (Grigg 1993). Detached colonies are rarely able to reattach.

The life history attributes of deep corals makes them highly vulnerable to habitat damage associated with fishing gear and overexploitation in unmanaged coral fisheries (Table 4.2). Many year classes are exposed to effects at the same time. During intensive periods of indiscriminate fishing using bottom damaging gear, decades of accumulated coral growth can be lost (Grigg 1993).

Fishing effects

Bottom Trawling

Mobile bottom-tending gear (e.g., trawls, dredges) are banned in the U.S. Pacific Islands Region. From 1967 to 1975, Soviet and Japanese trawlers fished the seamounts at the south end of the Emperor Chain (e.g., Coco Seamount, Milwaukee Seamount, Colahan Seamount) and some of the seamounts at the north end of the Hawaiian

Archipelago, including seamounts that were later designated as part of the U.S. exclusive economic zone (e.g., Hancock Seamount, Seamount 10, Seamount 11, Ladd Seamount) (Uchida and Tagami 1984). The primary fishing target was *Pseudopentaceros wheeleri* (armorhead) and *Beryx* spp. (alfonsinos)(Uchida and Tagami 1984). In 2003, submersible dives at Seamount 11 found a large area with coral stumps and no new colonization (A. Baco pers. obs). The destruction was confined to a large swath within a fairly large precious coral bed (previously unknown). It could not be determined if this affected area was the result of mobile bottom-tending gear used in the early 1970s but if so, recovery clearly requires decades.

Longline fishing

Bottom longlining is not permitted in the Pacific Islands Region. Pelagic longlining for tuna and swordfish is permitted and is the region's largest fishery. Longlines must be set at least 25 miles, and in most cases 50–75 miles from emergent parts of the Hawaiian Archipelago (WPFMC 1991). This regulation was adopted to prevent conflicts with the coastal trolling fishery but it also reduces the possibility that the gear will affect deep corals on the slopes and seamounts of the Hawaiian Ridge. One exception is Cross Seamount located ~ 100 miles south of Oahu. A popular fishing site for monofilament handline fishing and some longline activity, it has accumulated numerous large fragments of monofilament line draped over the summit (F. Parrish pers. obs). Some of these line fragments have been seen entangled in *Gerardia* sp. colonies (A. Baco pers. obs.) and other coral trees appear to have been damaged. As this is the only location that impacts to deep coral from monofilament fishing have been documented the assigned impact rating is "Low."

Traps

Bottom-set traps have been used to catch lobster and shrimp in the Hawaiian Archipelago. The Northwestern Hawaiian Islands trap fishery for *Panulirus marginatus* (Hawaiian spiny lobster) and *Scyllarides squammosus* (slipper lobster) is now closed, but had always operated in waters shallower than deep coral habitat (Polovina 1994, Dinardo and Moffitt 2007). Trap fishing for the deepwater shrimp *Heterocarpus laevigatus* and *Heterocarpus ensifer* is a small-scale pulse fishery limited to the main Hawaiian Islands that has landed 680 metric tons since the fishery's inception in 1984 (PIFSC IR-06-010). The shrimp trapping overlaps the depth range of deep corals (Ralston and Tagami 1992; Moffitt and Parrish 1992), but actual impacts to deep corals have not been documented. Shrimp have been observed associated with hard bottom features (Moffitt and Parrish 1992) and if fishers seek hard bottom to set their traps, there is potential for damage to deep corals. In Table 4.2, the overall gear impact rating of shrimp trapping was classified "Low" because of the small size and localized nature of the fishery. However if the fishery expands the potential impacts to deep corals would be an important consideration. There are no other recognized trap fisheries operating in the U.S. Western Pacific Islands and if any recreational or artesianal trapping is happening, it is at a very small scale and in shallow depths.

Other

Fishing for reef species and bottom fish typically rely on spearing and hook and line fishing. Spearfishing is largely constrained to the shallowest depths and is unlikely to have an effect on deep corals. Corals might be damaged by the 3-kg bottom weight used to lower handlines for bottom fishing or might be snagged by the attached hooks. However, visual surveys from submersibles have inspected popular bottom fishing sites in the main and Northwestern Hawaiian Islands for fishing impacts and have found little or no derelict gear (Kelley et al. 2006), and there are no reports of coral bycatch (WPFMC 2005).

Effects of other human activities

Coral Harvesting

The commercial harvest of coral is the best documented effect to black corals and precious corals (pink, red, and gold) within the Hawaiian Archipelago. Coral harvesting has been subject to management under both federal and state regulations since the 1980s. Commercial harvest of black coral has always been selective, collected by scuba divers using hand tools. The deeper precious coral beds were fished initially using nonselective tangle net dredges, but regulations now require the use of selective methodologies such as a submersible (Figure 4.8). Commercial harvesting of black and precious corals has not been reported elsewhere in the U.S. Pacific outside of the Hawaiian Archipelago.

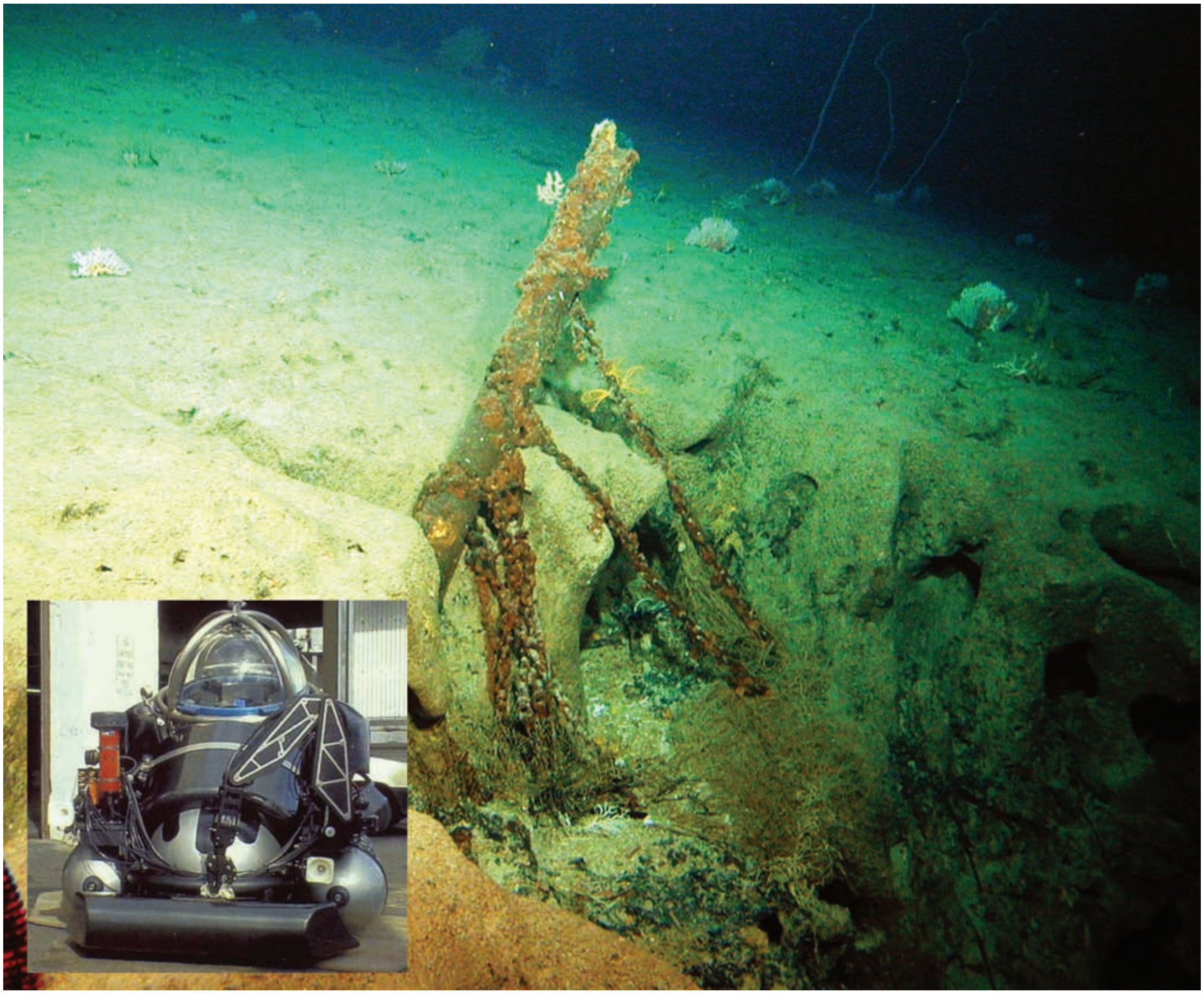

Figure 4.8. A derelict coral dredge lost during the earliest days of the fishery (Dredge photo credit: A. Baco, WHOI). Inset is the Deepworker submersible which was the most recent harvesting tool employed. Photo credit: American Deepwater Engineering.

Maui Divers, Inc. established the small black coral industry in 1960 and has kept the fishery operating at varying levels continuously to the present. Limited commercial harvest of black coral also occurred in two other beds off Hawaii and Kauai. State records indicate a mean annual harvest of black coral at 1014 kg yr^{-1} from 1981 to 1997 (Grigg 2001). Between 1999 and 2002 there was an increase in demand accompanied by an increase in harvesting (Grigg 2004). This fishery often operates with fewer than three fishers so confidentiality prevents disclosure of annual data. Aggregating data into 7-year bins showed landings increased from 1985 to 2005 with the 1999-2005 7-year bin at 22 mt which is more than double the prior 7-year bins (WPRFMC 2006). Much of this increase has been attributed to improved efficiency in fishing due to the availability of detailed bathymetric maps and adoption of GPS positioning. Although 11 genera of antipatharians have been reported in international trade, only three species (*Antipathes* cf. *curvata* {formerly *Antipathes dichotoma*} *Antipathes grandis* and *Myriopathes ulex)* have been commercially harvested in Hawaiian waters, with >90% of the harvested coral consisting of *A. c.f. curvata.* Other black coral species known to exist in this region are found in deeper waters and are not considered to be of commercial grade (Grigg 1993).

In 1965, a bed of commercial grade pink coral was discovered at about 400 m depth on the Milwaukee Banks in the Emperor Seamount Chain. In 1966, *Corallium secundum* was also discovered in the Makapuu Bed off Oahu, and a small group of fishermen dredged the bed using tangle nets (Grigg 1993). Maui Divers of Hawaii began using a manned submersible to selectively harvest pink, gold, and bamboo coral from this bed. They removed a total of 8227 kg of pink coral and 2097 kg of gold coral between 1973 and 1978 and then discontinued fishing as a result of high operating costs (Grigg 1993). Pink corals were also harvested in 1988 from Hancock Seamount using nonselective gear, although only 450 kg of *C. secundum* were obtained, most of which were considered poor quality (Grigg 1993). In 1978, an undescribed species of *Corallium* was discovered at Midway Grounds (Emperor Seamounts) at depths of 900–1500 m. This resulted in a "coral rush," with more than 100 boats from Japan and Taiwan operating in this area. Total yield exceeded 300 metric tons from 1979 to 1984 and then dropped off because of resource depletion (Grigg 1993).

In 1999, a Hawaii-based marine salvage and engineering company bought two deep-worker submersibles and began commercial harvesting of deep corals at the Makapuu and Keahole coral beds. Operations targeted pink, red, and gold corals. Harvesting ended in 2001, when their first coral auction indicated the price of the coral was too low to make submersible operations cost effective, and potential harvesting grounds in the Northwestern Hawaiian Islands were eliminated as a result of Presidential Executive Order 13196, which formed the Coral Reef Ecosystem Reserve in the Northwestern Hawaiian Islands (Grigg 2002). Because the fishery is made up of a single company, confidentiality prevents reporting of landings data. However the permitted quota was not filled at either of the two beds where corals were harvested. Grigg (2002), working closely with the industry, reported removal of 60% of the allowed coral quota (1,216 kg) at the Makapuu Bed and 20% (211 kg) at the Keahole Bed. The precious coral fishery remains dormant today.

Illegal coral dredging

Currently, the threat of illegal coral dredging is thought to be remote. It is included here because foreign fishing vessels were documented illegally coral dredging in the remote Northwestern Hawaiian Islands in the early 1970s (Grigg 1993). Currently, there is no evidence or even rumors of such illegal activity. However, much of the Pacific region is remote and unpopulated and any such activity could go undetected. Given the slow growth of deep corals and low recruitment rates, even brief periods of illegal dredging could have lasting effects.

Invasive species

In 1972, the alien soft coral *Carijoa riisei* (Family Clavulariidae) was found in the fouling community of Pearl Harbor (Englund 2002). Originally thought to have colonized from the tropical Atlantic, recent genetic work (Samuel Kahng pers. comm.) suggests it arrived from elsewhere. It has and continues to spread to other suitable areas in Hawaii with high flow and low light (Figure 4.9). In 2001 deepwater surveys of the Auau Channel black coral beds using submarines revealed that more than 50% of the black coral, particularly the deeper, large reproductive colonies, were overgrown and killed by *Carijoa* (Kahng and Grigg 2005). However, *Carijoa* was rare on black coral trees in waters shallower than 75 m (Boland and Parrish 2005). Light levels are thought to be too high for *Carijoa* to colonize the shallower black coral trees. This invasive coral has been identified as a risk to the black coral fishery. Historically, black coral trees that were too deep to be harvested by divers were thought to serve as a de facto reserve for the fishery. With the recent discovery that many of the deep colonies have been killed by *Carijoa,* current management practices are being reviewed (Grigg 2004). Preliminary surveys of black

Figure 4.9. The invasive gorgonian octocoral *Carijoa riisei*, that infests the deeper black corals of the Auau Channel beds.Photo credit: F. Parrish, NOAA Fisheries.

coral beds on Kauai and the island of Hawaii have not found an infestation of *Carijoa*. The occurrence of *Carijoa* or other invasive species on deep corals elsewhere in the Pacific has not been reported.

VII. MANAGEMENT OF FISHERY RESOURCES AND HABITATS

The Pacific Islands Region has a 25-year history of managing deep corals associated with its Precious Coral Fishery Management Plan. The plan was the first fishery management plan approved by NMFS when the Western Pacific Fishery Management Council was established as part of the national network of fishery councils (WPFMC 1980). The plan was implemented in September 1983 (48 FR 39229).

Management of fishery resources and habitats

Historically, research has been focused on taxonomy (Grigg and Bayer 1976), coral assessments and estimates of age and growth to support the information needs to manage the fishery (Grigg 1965, 1974, 1988b, 1993, 2001). In recent years, management research has expanded to include work assessing the connectivity of coral taxa across the Hawaiian Archipelago (Baco and Shank 2005; Baco et al. 2006; Baco in prep.) and potential ecological associations between corals and other fauna (Parrish et al. 2002; Boland and Parrish 2005; Parrish 2006; Baco and Shirley in prep.). Studies are now focusing on the threat *Carijoa riisei* presents to the black coral stock (Grigg 2002; Kahng and Grigg 2002). Replanting corals has been discussed as a means to mitigate impacts to the black coral stock from *Carijoa* and coral harvesting. Some preliminary "replanting" research has been conducted with Hawaiian black coral (Montgomery 2002), and coral harvesters have expressed interest in continuing the work. The expeditions that supported all this research established study sites, deployed thermographs, and marked colonies for future remeasurement to validate growth and monitor the deep coral ecosystem.

Mapping Research

Future coral research will have the benefit of recent multibeam sonar mapping efforts. Supplementing earlier sidescan sonar (GLORIA system) and single beam sonar mapping efforts, multibeam products, including detailed bathymetry and backscatter imagery, have been made for the Hawaiian archipelago and other portions of the U.S. Pacific (Products by John Smith at HURL; Miller et al. 2003; Parke and Wang 2005). These efforts will provide a fundamental bathymetric context that future coral surveys will be able to use to infer the likelihood of deep corals. Efforts are currently underway to test laser-line scan survey technology on the black coral beds of the main Hawaiian Islands as a more promising means of directly surveying the colony abundance of deep corals.

Fisheries Management Council

The Western Pacific Fishery Management Council (WPFMC) has responsibility for preparing fishery management plans (FMPs) for the fisheries in the U.S. exclusive economic zone (EEZ) of the Pacific Islands Region. Because of the steep relief of many Pacific Islands, deep corals also occur within state and territory waters, and fisheries can also be governed by state and territory laws and regulations. The Freely Associated States are sovereign countries and management of fisheries within their EEZs is governed by their own laws and regulations. WPFMC, an early leader in managing habitat impacts of fishing gears, prohibited demersal fish trawls, bottom-set longlines, and bottom-set gillnets throughout the U.S. Pacific Island EEZ in 1983. The State and territorial laws of Hawaii, Guam, CNMI, and American Samoa all prohibit the use of demersal fish trawls within their waters. The sovereign territories of Kingman Reef, Palmyra Atoll, Jarvis Island, Howland Island, Baker Island, Midway Island, and Rose Atoll are National Wildlife Refuges administered by the U.S. Fish and Wildlife Service, while Wake Island and Johnston Atoll are managed by the Department of Defense. Commercial fishing is not allowed within the Fish and Wildlife Refuges. Thus, throughout the region, both shallow and deep corals have been largely spared impacts from trawling, at least within the last 25 years.

Directed Harvest

The Precious Coral FMP and its regulations classify known coral beds within the western Pacific region and designate the harvesting method and amount of corals that can be harvested from each bed. All the known coral beds are in the Hawaiian Archipelago but the FMP includes provisions for exploratory fishing in other areas of the U.S. Pacific. The beds are classified as: 1) Established Beds, 2) Conditional Beds, 3) Refugia Beds, and 4) Exploratory Permit Areas. Established beds have a history of harvest for which maximum sustainable yield (MSY) has been determined. Makapuu is the only designated Established Bed although the Auau black coral bed is in the process of being designated as established. Conditional beds have MSYs estimated based on their perceived size relative to established beds. There are four conditional beds: Keahole Point, Kaena Point, Brooks Banks and 180 Fathom Bank. The WESTPAC Bed is designated as a refugia bed, where no harvest is permitted. Exploratory permit areas include four unexplored portions of the EEZ around Hawaii, Guam and CNMI, American Samoa, and all remaining U.S. Island Possessions. The FMP, as amended in 2002, prohibits the use of nonselective gear (e.g., tangle nets, dredges) throughout the management area. Black coral is primarily found in State waters and the State and the WPFMC jointly manage the resource. Quotas and minimum size limits are monitored through mandatory reporting to NMFS and the Hawaii State Division of Aquatic Resources using coral landing logs and buyer reports.

Currently, two precious coral issues are progressing through the WPFMC process. The first is reconciling coral lifespan estimates derived from radiometry studies (Roark et al. 2006) with prior estimates made from the size structure distribution of coral colonies and ring counts from basal stem cross sections. Of the three commercial corals, the black coral (*Antipathes* cf. *curvata*) radiometric estimates were consistent with growth rates estimated from size structure data (Grigg and Bayer 1976). The radiometric life span of pink coral was twice prior estimates, and gold coral (*Gerardia* sp.) was estimated at more than an order magnitude longer lived than prior growth estimates (Grigg 2002). This has prompted the WPFMC to put a 5-year moratorium on the fishing of gold coral until the conflicting lifespan data can be resolved. The second issue is concern that the Maui black coral bed may be experiencing reduced recruitment (Tony Montgomery, State of Hawaii, unpublished data; WPFMC 2006). This uncertainty combined with the loss of a portion of the stock to *Carijoa riisei* leaves today's biomass at least 25% lower than assessments in 1976 (Grigg 2004).

Closed areas

As noted above, all U.S. State and Federal waters in the Pacific Islands are closed to trawling and dredging—the fishing techniques most destructive to deep corals. Additional restrictions on fishing and other potentially harmful activities are in place in the National Wildlife Refuges, Papahānaumokuākea Marine National Monument, and in marine protected areas within state or territory waters.

The only area that was specifically closed to protect deep corals was WESTPAC Bank (located N.W. of Nihoa) in the Northwestern Hawaiian Islands. It was set aside by the precious coral FMP as a refuge from coral harvesting. Despite some interest, domestic precious coral fishing has never occurred in the Northwestern Hawaiian Islands. On determining that monk seals were visiting precious coral beds, the WPFMC proposed expanding the refuge to include areas where seals were visiting. Superseding this move, the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve was established in 2001 by Executive Order (No. 13178 and No. 13196) and prohibited most commercial fishing, including all harvesting of deep corals in the Reserve. In 2006, while the Northwestern Hawaiian Islands Reserve was undergoing the designation process to become a national marine sanctuary, it was proclaimed a national monument by Presidential Order under the Antiquity Act of 1906 and renamed Papahānaumokuākea Marine National Monument. Within the main Hawaiian Islands and elsewhere in the Pacific, marine protected areas have not been established specifically for the purpose of protecting deep coral communities. However, there is interest from managers and coral harvesters to establish a closed area off Maui specifically for black coral to serve as a reproductive reserve and a biological reference site.

Minerals Management Service

Oil or gas exploration does not occur in the Pacific Islands Region. Historically, some research has focused on the prospect of mining manganese nodules that are formed at abyssal depths. Recently, interest in cobalt-rich manganese mining has resurged and large areas of the Pacific seabed, some of which include U.S. Pacific Islands and seamounts, are part of the potential mining areas (International Seabed Authority www.isa.org.jm/en/seabedarea/default.

asp). Further studies of these cobalt-rich regions to determine deep-coral abundance and potential mining impacts should be considered a high priority.

VIII. REGIONAL PRIORITIES TO UNDERSTAND AND CONSERVE DEEP CORAL COMMUNITIES

The priorities for future work can be divided into the following: 1) mapping and species inventory of deep corals, and 2) determining the important physiological and ecological components of deep coral ecosystems. The inherently fragile and patchy nature of deep corals means that determining where they are found is a primary goal. Good success has been achieved using available mapping, remotely operated vehicles (ROV), and submersible infrastructure. This should continue and extend out to the more remote areas of the U.S. Pacific Islands Region. Also, research is needed to validate promising new tools to assess coral stocks with an initial focus of using such gear at sites previously surveyed using visual methods.

1) *Highest mapping and assessment priorities*

- Assessments in the remote Pacific—Historically, most research has occurred in and around the Hawaiian Archipelago, leaving American Samoa, Guam, CNMI, and the rest of the western Pacific unstudied. Baseline assessments are needed for these other areas, particularly those that may be affected by cobalt-manganese mining or fishery activities. Documenting areas with extensive coral resources will permit more focused enforcement and conservation effort. These assessments will also provide the DNA material for connectivity work, provide samples to improve taxonomy and systematics of deep corals, and provide an invaluable test to current theories on deep coral biogeography.
- Deeper surveys—Although the Hawaiian Archipelago has had some studies, few baseline assessments of deep corals have occurred outside of precious corals depth and none below 1800 m. There is a need to survey deeper habitats to better determine the species ranges, biodiversity, and abundance of deep corals.
- Taxonomy—Critical to all of the assessment and ecology studies will be a dedicated effort to improve the taxonomy and systematics of deep corals, and to increase the number of people trained to identify these corals. There are very few deep coral experts in the world and there are currently more groups of deep corals needing revision and new species needing description than these taxonomists can complete in their lifetimes.
- Coral recovery studies—Beds that have been commercially harvested or impacted by fishing gear and coral harvesting should be periodically reassessed to determine whether or not the coral taxa are recovering. The seamounts that were subjected to bottom trawling or illegal harvesting more than 30 years ago should be surveyed for signs of coral recovery.

2) *Physiological and ecological components of the deep coral ecosystem*

- Environmental parameters for deep corals—The patchy nature of deep corals, even in areas with similar substrate, relief, and depth implies that their distribution is influenced by other biological or environmental factors. Understanding the oceanographic factors that influence coral distributions will be fundamental to evaluating deep corals as a climate record as well as predicting where they might occur in unexplored areas.
- Life history, population connectivity, and biogeography—There is a need to understand more about the life history, reproduction, recruitment, growth, and dispersal abilities of deep corals; how the populations are connected within island/seamount chains and between them, and how the islands and seamounts of the U.S. Pacific are connected genetically and biogeographically to other parts of the Pacific.
- Species associations—The ecological contribution of corals to their associated community needs greater attention, particularly the invertebrates, which are more likely to be dependent on the coral colonies. Subphotic fish communities are likely to be different in the remote regions of the Pacific and may be more tightly associated with deep corals.
- The ecological impact of *Carijoa riisei*—*Carijoa riisei* represents the most clear and present threat to the stock of black coral and

has important implications to the black coral fishery. Research is needed to identify and understand possible ecological changes to the community and develop means to limit the spread of *Carijoa riisei* to other black coral habitats. Some research should be conducted to determine the feasibility of remediation efforts for black coral through replanting programs.

IX. CONCLUSIONS

- ❑ Deep corals occur throughout the U.S. Pacific but only the Hawaiian Archipelago and Line Islands have been the subject of any surveys. Coral habitat is patchy, suggesting at least a basic need for suitable bottom type and conditions of rapid flow. The gradients in dissolved oxygen, temperature, suspended particulates, etc., are less understood and are a priority for future work. Available surveys indicate coral beds dense with colonies that cover large areas are the exception. Given the region has little history of trawling and mobile bottom-tending gear, it is reasonable to assume this is the natural condition.

- ❑ Hawaiian fish are known to opportunistically use the corals as shelter and to some degree they co-occur with corals in high flow habitats. It is not known how the fish behave with deep corals in the other parts of the Pacific. Invertebrates are largely unstudied and the degree of their association with deep corals is unknown but likely to be greater.

- ❑ Currently, the greatest threat to corals is the potential for spread of the invasive species *Carijoa riisei* from the Auau channel to other black coral beds on Kauai and Hawaii. Following that, the harvesting in the 3 beds where the coral fishery operates needs to be closely monitored. For the black coral bed in the Auau channel, attention is needed because of the unanticipated loss of black coral to *Carijoa riisei*. At Makapuu, the regrowth of pink coral has been documented once and should be checked for continued resilience. The Keahole bed was targeted for red and gold coral, and its prospects for resilience are as yet unproven. Finally, the impacts to deep corals from derelict handlines/longlines at Cross Seamount and shrimp trapping in the main Hawaiian Islands should be assessed.

- ❑ Many of the new coral beds that have been identified in the Northwestern Hawaiian Islands are protected as part of the Papahānaumokuākea Marine National Monument. Being remote from the anthropogenic influences of the main Hawaiian Islands make them important biological reference sites for future research.

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Appendix 4.1. List of known species of ceep corals from the U.S. Pacific Islands. All species listed are found in Hawaii except one octocoral, *Keroeides koreni* and several antipatharins as noted. List for octocorals and scleractinians in Hawaii based primarily on unpublished list compiled by Dr. Stephen Cairns, Smithsonian Institution, with additions from recent Pisces cruises led by A. Baco and additions for non-Hawaiian islands based on cited literature. List for antipatharians from Hawaii and Guam unpublished list compiled by and courtesy of Dr. Dennis Opresko.

* = depth range known from full range for species, including outside chapter region

** = depth range known from 2 or more specimens from Hawaii, Christmas, Line Islands, etc

*** = depth from a single individual from Hawaii, usually the holotype

Higher Taxon	Species	Distribution	Depth Range (m)	References
Phylum Cnidaria				
Class Anthozoa				
Subclass HExacorallia (Zoantharia)				
Order Scleractinia				
Family Anthemiphylliidae	*Anthemiphyllia macrolobata*	HI Islands	369***	Cairns, 1999
	Anthemiphyllia pacifica	HI Islands & Bikini Atoll, RMI	205-296**	Vaughan, 1907, Cairns, 1984
Family Caryophylliidae	*Anomocora* sp. cf. *A. fecunda*	HI Islands	201-271**	Pourtalès, 1871, Cairns, 1984
	Bourneotrochus stellulatus	HI Islands	274-336**	Cairns, 1984
	Caryophyllia atlantica	HI Islands	1602**	Duncan, 1873, Cairns, 1984
	Caryophyllia hawaiiensis	HI Islands	44-388**	Vaughan, 1907, Cairns, 1984
	Caryophyllia marmorea	HI Islands	331-337**	Cairns, 1984
	Caryophyllia octopali	HI Islands	457-627**	Vaughan, 1907, Cairns, 1984
	Caryophyllia rugosa	HI Islands	137-439**	Moseley, 1881, Cairns, 1984
	Caryophyllia sp. cf. *C. ambrosia*	HI Islands	56-206**	Alcock, 1898, Cairns, 1984
	”Ceratotrochus” laxus	HI Islands	583-678**	Vaughan, 1907
	Coenosmilia inordinata	HI Islands	244-322**	Cairns, 1984
	Conotrochus funicolumna	HI Islands	165-600**	Alcock, 1902, Cairns, 1984
	Crispatotrochus rubescens	HI Islands & Christmas Island, Line Islands	197-634**	Moseley, 1881, Cairns, 1984
	Deltocyathus sp. cf. *D. andamanicus*	HI Islands	274-518**	Alcock, 1898, Cairns, 1984

Higher Taxon	Species	Distribution	Depth Range (m	References
	Desmophyllum dianthus	HI Islands		Esper, 1794
	Paracyathus molokensis	HI Islands	161-260**	Vaughan, 1907
	Trochocyathus aithoseptatus	HI Islands	371-454**	Cairns, 1984
	Trochocyathus burchae	HI Islands	64***	Cairns, 1984
	Trochocyathus gardineri	HI Islands	274-470**	Vaughan, 1907, Cairns, 1984
	Trochocyathus mauiensis	HI Islands	174-278**	Vaughan, 1907
	Trochocyathus oahensis	HI Islands	75-571**	Vaughan, 1907, Cairns, 1984
	Trochocyathus patelliformis	HI Islands	1020***	Cairns, 1999
	Trochocyathus rhombocolumna	HI Islands	110-530*	Alcock, 1902
Family Dendrophylliidae	*Balanophyllia desmophyllioides*	HI Islands	143-406**	Vaughan, 1907
	Balanophyllia diomedeae	HI Islands	110-307**	Vaughan, 1907, Cairns, 1984
	Balanophyllia gigas	HI Islands	90-640*	Moseley, 1881
	Balanophyllia laysanensis	HI Islands	238-271**	Vaughan, 1907
	Cladopsammia echinata	HI Islands	295-470**	Cairns, 1984
	Cladopsammia eguchii	HI Islands		Wells, 1982
	Eguchipsammia gaditana	HI Islands	244-470**	Duncan, 1873, Cairns 1984
	Eguchipsammia fistula	HI Islands		Alcock, 1902
	Eguchipsammia serpentina	HI Islands	269-362**	Vaughan, 1907
	Enallopsammia rostrata	HI Islands	362-583**	Pourtalès, 1878, Cairns, 1984
	Endopachys grayi	HI Islands	37-274**	Milne-Edwards & Haime, 1848a & b, Cairns, 1984
Family Flabellidae	*Flabellum marcus*	HI Islands & NW of Wake Island	1261-1602**	Keller, 1974, Cairns, 1984
	Flabellum pavoninum	HI Islands	183-517**	Lesson, 1831, Cairns, 1984
	Flabellum vaughani	HI Islands	232-369**	Cairns, 1984
	Javania exserta	HI Islands	400***	Cairns, 2006
	Javania fuscus	HI Islands	13-271**	Vaughan, 1907
	Javania insignis	HI Islands & Christmas Island, Line Islands	52-825**	Duncan, 1876, Cairns, 1984

Higher Taxon	Species	Distribution	Depth Range (m	References
	Javania lamprotichum	HI Islands & Johnston Atoll	244-322**	Moseley, 1880, Cairns, 1984
	Placotrochides minuta	HI Islands	119-291***	Feinstein and Cairns, 1998, Cairns 2006
	Polymyces wellsi	HI Islands	440-858**	Cairns, 2006
Family Fungiacyathidae	*Fungiacyathus fissilis*	HI Islands	212-503**	Cairns, 1984
	Fungiacyathus fragilis	HI Islands	1762-2056**	Sars, 1872, Cairns, 1984
Family Gardineriidae	*Gardineria hawaiiensis*	HI Islands	369-541**	Vaughan, 1907, Cairns, 1984, 2006
Family Guyniidae	*Guynia annulata*	HI Islands	64-384**	Duncan, 1872, Cairns, 1984
Family Micrabaciidae	*Letepsammia formosissima*	HI Islands	109-470**	Moseley, 1876, Cairns, 1984
Family Pocilloporidae	*Madracis kauaiensis*	HI Islands	362-538**	Vaughan 1907, Cairns 2006
Family Oculinidae	*Madrepora kauaiensis*	HI Islands	362-538**	Vaughan, 1907, Cairns, 1984
	Madrepora oculata	HI Islands	627-750**	Cairns, 1984
Family Turbinoliidae	*Deltocyathoides orientalis*	HI Islands	439-494**	Duncan, 1876, Cairns 1984, Cairns 2006
Family Stenocyathidae	*Stenocyathus vermiformis*	HI Islands & S. Pacific Seamounts	439**	Pourtalès, 1868, Cairns, 1982,
				Cairns, 1984
Order Antipatharia				
Family Antipathidae	*Antipathes grandis*	HI Islands		Verrill, 1928
	Antipathes sp., cf. *A. curvata*	HI Islands		van Pesch, 1914
	Antipathes n. sp., cf. *A. dichotoma*	HI Islands		Pallas, 1766
	Antipathes sp. cf. *A. flabellum*	Guam		Pallas, 1766
	Antipathes sp., cf. *A. spinuilosa*	Guam		Schultze, 1896
	Antipathes intermedia	HI Islands	347-366***	Brook, 1889, Grigg and Opresko, 1977
	Cirrhipathes anguina	HI Islands	25-40***	Dana, 1846, Grigg and Opresko, 1977
	Cirrhipathes contorta	Guam		
	Cirrhipathes propinqua	Guam		
	Cirrhipathes spiralis	HI Islands		Linnaeus, 1758, Grigg and Eldridge, 1975

Higher Taxon	Species	Distribution	Depth Range (m	References
	Stichopathes echinulata	HI Islands	305-565***	Brook, 1889, Grigg and Opresko, 1977
Family Aphanipathidae	*Aphanipathes sarothamnoides*	Guam		Brook, 1889
	Acanthopathes undulata	HI Islands	110-490**	van Pesch, 1914, Grigg and Opresko, 1977
Family Cladopathidae	*Trissopathes pseudotristicha*	HI Islands & Channel Islands	326-4539**	Opresko, 2003
	Trissopathes tetracrada	HI Islands	375-425**	Opresko, 2003
Family Leiopathidae	*Leiopathes glaberrima*	HI Islands		Esper, 1792, Opresko, 1974
	Leiopathes n. sp.	HI Islands	403-471**	Prelim. ID by Opresko, Pisces Cruise 2003 &2004
Family Myriopathidae	*Myriopathes ulex*	HI Islands & Guam		Ellis and Solander, 1786, Grigg and Eldridge, 1975
	Myriopathes sp., cf. *M. japonica*	HI Islands		Brook, 1889
	Cupressopathes abies	Guam		Linnaeus, 1758
	Antipathella sp., cf. *A. subpinnata*	HI Islands	455-460***	Ellis and Solander, 1786, Grigg and Opresko, 1977
Family Schizopathidae	*Bathypathes alternata*	HI Islands	1195-1744**	Brook, 1889, Pisces Cruise 2003
	Bathypathes conferta	HI Islands	380***	Brook, 1889, Grigg and Opresko, 1977
	Bathypathes patula	HI Islands		Brook, 1889, Unpubl record at USNM
	Stauropathes staurocrada	HI Islands & Johnston Atoll	220-441, 1400-1700**	Opresko, 2002
	Stauropathes sp.	HI Islands	604***	Prelim. ID by Opresko, Pisces Cruise 2003
	Umbellapathes helioanthes	HI Islands	1205-1383**	Opresko 2005
	Umbellapathes, new species B	HI Islands	742-744***	Prelim. ID by Opresko, Pisces cruise 2004
	Dendropathes bacotaylorae	HI Islands	408***	Opresko 2005
Order Zoanthidea				
	Zoanthid blue	HI Islands	352-415**	Chave and Malahoff, 1998

Higher Taxon	Species	Distribution	Depth Range (m	References
	Zoanthid tan	HI Islands	500-1910**	Chave and Malahoff, 1998
	Gerardia sp.	HI Islands	343-577**	Ryland and Baco in prep., Chave and Malahoff, 1998
	Parazoanthus sp. 1	HI Islands	343-460**	Chave and Malahoff, 1998
	Parazoanthus sp. 2	HI Islands	332-1025**	Chave and Malahoff, 1998
Subclass Octocorallia				
Order Alcyonacea				
Family Alcyoniidae	*Anthomastus fisheri*	HI Islands	356-462**	Bayer, 1952, Chave and Malahoff, 1998
	Anthomastus (Bathyalcyon) robustus	HI Islands		Versluys, 1906, fide Williams
	Anthomastus granulosus	HI Islands	20-201**	Kukenthal 1910, Bayer, 1952
	Inflatocalyx sp.	HI Islands		fide Williams
Family Clavulariidae	*Carijoa riisei*	Invasive, HI Islands		Duch. And Mich., 1860
	Clavularia grandiflora	HI Islands	966*	Nutting, 1908, Bayer, 1952
	Telestula corrugata	HI Islands	914*	Nutting, 1908, Bayer, 1952
	Telestula spiculicola	HI Islands	518-616*	Nutting, 1908, Bayer, 1952
	Telestula spiculicola robusta	HI Islands		Bayer, 1952
Family Nidaliidae	*Nidalia* sp.	HI Islands		fide Williams
	Siphonogorgia alexanderi	HI Islands	223-283*	Nutting, 1908, Bayer, 1952
	Siphonogorgia collaris	HI Islands	144*	Nutting, 1908, Bayer, 1952
Order Gorgonacea				
Family Acanthogorgiidae	*Acanthogorgia* sp. cf. *A. striata Nutting, 1911*	HI Islands	215-564**	Grigg and Bayer, 1976
	Acanthogorgia n. sp.	HI Islands		Muzik, 1979
	Acanthogorgia sp. cf. *A. paramuricata*	HI Islands	350-396**	Stiasny, 1947, Grigg and Bayer, 1976
	Acanthogorgia sp.	HI Islands	1295***	Berntson et al., 2001
	Cyclomuricea flabellata	HI Islands	71-396**	Nutting, 1908, Grigg and Bayer, 1976
	Muricella tenera	HI Islands	237-2533*	Ridley, 1884, Nutting, 1908
Family Anthothelidae	*Anthothela nuttingi*	HI Islands	340-465, 1387-1820**	Bayer, 1956, Grigg and Bayer, 1976

Higher Taxon	Species	Distribution	Depth Range (m	References
	Antothela n. sp. 1	HI Islands	1319***	Prelim. ID by Cairns, Pisces Cruise 2003
	Antothela n. sp. 2	HI Islands	1804***	Prelim. ID by Cairns, Pisces Cruise 2003
Family Chrysogorgiidae	*Chrysogorgia arborescens*	HI Islands	722-914*	Nutting, 1908
	Chrysogorgia chryseis	HI Islands	732***	Bayer and Stefani, 1988, Berntson et al., 2001
	Chrysogorgia delicata	HI Islands	536-1463*	Nutting, 1908
	Chrysogorgia elegans	HI Islands	433-634*	Verrill, 1883, Nutting, 1908
	Chrysogorgia flavescens	HI Islands	1688-1977*	Nutting, 1908
	Chrysogorgia geniculata	HI Islands	146-616*	Wright & Studer, 1889, Nutting, 1908
	Chrysogorgia sp. cf. *C. japonica*	HI Islands	750-1050**	Wright & Studer, 1889, Grigg and Bayer, 1976
	Chrysogorgia paillosa	HI Islands	704-1858*	Kinoshita, 1913, Grigg and Bayer, 1976, Nutting, 1908
	Chrysogorgia scintillans	HI Islands	580-2050**	Bayer and Stefani, 1988, Chave and Malahoff, 1998
	Chrysogorgia stellata	HI Islands	649-678*	Nutting, 1908
	Chrysogorgia sp. cf. *C. stellata*	HI Islands	646-675, 830-922*	Nutting, 1908, Grigg and Bayer, 1976, Bayer and Stefani 1988
	Chrysogorgia n. sp. (1/3R)	HI Islands	1204***	Prelim. ID by Cairns, Pisces Cruise 2003
	Chrysogorgia n. sp (2/5L)	HI Islands	691-742**	Prelim. ID by Cairns, Pisces Cruise 2004
	Iridogorgia superba	HI Islands	704-914*	Nutting, 1908, Grigg and Bayer, 1976
	Iridogorgia bella	HI Islands	750-1925**	Nutting, 1908, Chave and Malahoff, 1998
	Iridogorgia. n. sp.	HI Islands	1443***	Prelim. ID by Cairns, Pisces Cruise 2003
	Metallogorgia melanotrichos	HI Islands	183-1385*	Wright and Studer, 1889, Nutting, 1908
	Metallogorgia n. sp.	HI Islands	1805***	Prelim. ID by Cairns, Pisces Cruise 2003
	Pleurogorgia militaris	HI Islands	2142*	Nutting, 1908
	Radicipes spiralis	HI Islands	258**	Nutting, 1908, Grigg and Bayer, 1976

Higher Taxon	Species	Distribution	Depth Range (m	References
Family Coralliidae	*Corallium abyssale*	HI Islands	1829-2403***	Bayer, 1956, Bayer unpubl ms
	Corallium ducale	HI Islands		Bayer, 1955, Bayer unpubl ms
	Corallium kishinouyei	HI Islands	1145***	Bayer, 1996, Bayer unpubl ms
	Corallium laauense	HI Islands	365-580**	Bayer, 1956, Grigg and Bayer, 1976
	Corallium niveum	HI Islands	232-282***	Bayer, 1956, Bayer unpubl ms
	Corallium regale	HI Islands	365-719**	Bayer, 1956, Grigg and Bayer, 1976
	Corallium secundum	HI Islands	231-576**	Dana, 1846, Bayer, 1956, Grigg and Bayer, 1976, Pisces Cruise 2003
	Corallium imperiale	HI Islands	1096***	Bayer, 1955, Pisces Cruise 2003
	Corallium cf. *secundum*	HI Islands		Prelim. ID by Cairns, Pisces Cruise 2003
	Corallium laauense x halmahera	HI Islands		Prelim. ID by Cairns, Pisces Cruise 2003
	Corallium n. sp.	HI Islands		Prelim. ID by Cairns, Pisces Cruise 2003
	Paracorallium tortuosum	HI Islands	167-408**	Bayer, 1956, Grigg and Bayer, 1976
Family Gorgoniidae	*Eunicella* n. sp. *A*	HI Islands	275-495**	Grigg and Bayer, 1976
Family Isididae	*Acanella dispar*	HI Islands	275-445**	Bayer, 1990
	Acanella weberi	HI Islands		Nutting, 1910
	Isidella trichotoma	HI Islands	1920***	Bayer, 1990
	Isidella sp. *“5”*	HI Islands		Muzik museum id
	Isidella n. sp. (lyrate)	HI Islands	1808***	Prelim. ID by Cairns, Pisces Cruise 2003
	Keratoisis flabellum	HI Islands	346-465**	Nutting, 1908, Grigg and Bayer, 1976
	Keratoisis grandis	HI Islands	1344-1582*	Nutting, 1908
	Keratoisis n. sp.	HI Islands	305-565**	Grigg and Bayer, 1976
	Lepidisis nuda	HI Islands		Wright and Studer, 1889, Grigg and Bayer 1976
	Lepidisis olapa	HI Islands	215-665**	Muzik, 1978
	Lepidisis paucispinosa	HI Islands	539-631**	Wright and Studer, 1889, Nutting 1908, Muzik, 1978
	Lepidisis sp.	HI Islands	1425***	Berntson et al., 2001

Higher Taxon	Species	Distribution	Depth Range (m	References
Family Keroeididae	*Keroeides fallax*	HI Islands	238-245***	Bayer, 1956
	Keroeides koreni	Marshall Islands		Wright & Studer, 1889, Bayer, 1956
	Keroeides mosaica	HI Islands	167-465**	Bayer, 1956, Grigg and Bayer, 1976
	Keroeides pallida	HI Islands	146***	Hiles, 1899, Bayer, 1956
Family Paragorgiidae	*Paragorgia dendroides*	HI Islands	490-1910**	Bayer, 1956, Chave and Malahoff, 1998
	Paragorgia sp. cf. *P. regalis Nutting, 1912*	HI Islands	350-396**	Grigg and Bayer, 1976
	Paragorgia n. sp.	HI Islands	350-396**	Grigg and Bayer, 1976
Family Plexauridae	*Anthomuricea tenuispina*	HI Islands	428-531, 581-688**	Nutting, 1908, Grigg and Bayer, 1976
	Anthomuricea sp. cf. *A. divergens*	HI Islands	381-426**	Kükenthal, 1919, Grigg and Bayer, 1976
	Anthomuricea sp. cf. *A. reticulata*	HI Islands	362-421**	Nutting, 1910, Grigg and Bayer, 1976
	Anthomuricea n. sp. A	HI Islands		Muzik, 1979
	Bebryce brunnea	HI Islands	167-396**	Nutting, 1908, Grigg and Bayer, 1976
	Bebryce n. sp.	HI Islands		Muzik, 1979
	Muriceides sp. A	HI Islands		Muzik, 1979
	Muriceides sp. B	HI Islands		Muzik, 1979
	Filigella n. sp. *Thesea* n. sp.	HI Islands		Muzik, 1979
	Muriceides tenuis	HI Islands	232-362*	Nutting, 1908, Muzik, 1979
	Muriceides n. sp. A	HI Islands		Muzik, 1979
	Muriceides n. sp. B	HI Islands		Muzik, 1979
	New genus, n. sp.	HI Islands		Muzik, 1979
	Paracis horrida	HI Islands		Thomson & Henderson, 1906, Muzik, 1979
	Paracis miyajimai	HI Islands	362-531**	Kinoshita, 1909, Grigg and Bayer, 1976
	Paracis n. sp. A	HI Islands		Muzik, 1979
	Paracis spinifera	HI Islands	350-396**	Nutting, 1912, Grigg and Bayer, 1976
	Paramuricea HI Islandsensis	HI Islands	350-396, 924-1241**	Nutting, 1908, Grigg and Bayer, 1976

Higher Taxon	Species	Distribution	Depth Range (m	References
	Placogorgia n. sp.	HI Islands		Bayer unpubl ms
	Placogorgia sp. n. A	HI Islands		Muzik, 1979
	Placogorgia n. sp. B	HI Islands		Muzik, 1979
	Placogorgia sp. cf. *P. dendritica*	HI Islands	350-396**	Nutting, 1910, Grigg and Bayer, 1976
	Placogorgia sp.	HI Islands	335-375**	Grigg and Bayer, 1976
	Placogorgia sp. cf. *Ps. placoderma*	HI Islands	73, 182**	Nutting, 1910, Grigg and Bayer, 1976
	Pseudothesea sp. cf. *Ps. orientalis*	HI Islands	147, 350-396**	Thom & Hend, 1906, Grigg and Bayer, 1976
	Swiftia n. sp. 1	HI Islands	340-365**	Grigg and Bayer, 1976
	Swiftia n. sp. 2	HI Islands	350-396**	Grigg and Bayer, 1976
	Swiftia pacifica	HI Islands		Muzik 1979
	Thesea sp. cf. *T. ramosa*	HI Islands	313-399**	Nutting, ??, Grigg and Bayer, 1976
	Villogorgia arbuscula	HI Islands	315-412**	Wright & Studer, 1889, Grigg and Bayer, 1976
	Villogorgia n. sp. 1	HI Islands	350-396**	Grigg and Bayer, 1976
	Villogorgia n. sp. 2	HI Islands	350-396**	Grigg and Bayer, 1976
	Villogorgia n. sp. A	HI Islands		Muzik, 1979
	Villogorgia n. sp. B	HI Islands		Muzik, 1979
	Villogorgia n. sp. C	HI Islands		Muzik, 1979
Family Primnoidae	*Callogorgia formosa*	HI Islands		Kukenthal, 1907, Bayer, 1982
	Callogorgia gilberti	HI Islands	215-960**	Nutting, 1908, Grigg and Bayer, 1976
	Callogorgia n. sp.	HI Islands	350-396**	Grigg and Bayer, 1976
	Calyptrophora agassizii	HI Islands	781-1145**	Studer, 1894, Grigg and Bayer, 1976
	Calyptrophora angularis	HI Islands	1207-3292*	Nutting, 1908, Grigg and Bayer, 1976
	Calyptrophora clarki	HI Islands	12-1275	Bayer, 1951
	Calyptrophora japonica	HI Islands	216-432**	Gray, 1866, Grigg and Bayer, 1976
	Calyptrophora n. sp.	HI Islands	344-454**	Grigg and Bayer, 1976

Higher Taxon	Species	Distribution	Depth Range (m	References
	Calyptrophora wyvillei	HI Islands	744-823*	Wright, 1885, Nutting, 1908
	Calyptrophora n. sp. 1 (lyrate)	HI Islands	1078***	Prelim. ID by Cairns, Pisces Cruise 2003
	Calyptrophora n. sp. 2	HI Islands	1807***	Prelim. ID by Cairns, Pisces Cruise 2003
	Candidella gigantea	HI Islands	1720-1815**	Wright & Studer, 1889, Pisces cruise 2003
	Candidella helminthophora	HI Islands	38-1820**	Nutting, 1908, Grigg and Bayer, 1976
	Fanellia euthyeia	HI Islands		Bayer and Stefani, 1989
	Fanellia medialis	HI Islands		Bayer and Stefani, 1989
	Fanellia tuberculata	HI Islands		Versluys, 1906, Bayer, 1982
	Narella bowersi	HI Islands	1344-1937*	Nutting, 1908, Berntson et al., 2001, Grigg and Bayer, 1976
	Narella dichotoma	HI Islands		Versluys, 1906, Bayer ms: 27
	Narella sp. cf. N. megalepis	HI Islands	215-564**	Kinoshita, 1908, Grigg and Bayer, 1976
	Narella nuttingi	HI Islands	1350***	Bayer, 1997, Berntson et al., 2001
	Narella ornata	HI Islands	748-1007***	Bayer, 1995
	Narella studeri	HI Islands		Versluys, 1906
	Narella n. sp. 1	HI Islands	350-396**	Grigg and Bayer, 1976
	Narella n. sp. 2	HI Islands	353-417**	Grigg and Bayer, 1976
	Narella. n. sp. (unbranched)	HI Islands		Prelim. ID by Cairns Pisces Cruise 2003
	Paracalyptrophora n. sp.	HI Islands	367-398**	Prelim. ID by Cairns Pisces Cruise 2004
	Parastenella n. sp.	HI Islands	517***	Prelim. ID by Cairns Pisces Cruise 2004
	Plumarella n. sp.	HI Islands	384-432**	Grigg and Bayer, 1976
	Thouarella (A.) biserialis	HI Islands	439*	Nutting, 1908, Grigg and Bayer, 1976
	Thouarella (A.) regularis	HI Islands	183-722*	Wright and Studer, 1889, Nutting, 1908
	Thouarella sp. cf. *T. (T.) typica*	HI Islands	350-396**	Kinoshita, 1907, Grigg and Bayer, 1976

Higher Taxon	Species	Distribution	Depth Range (m	References
Order Pennatulacea				
Family Anthoptilidae	*Anthoptilum murrayi*	HI Islands	426-2286*	Kolliker, 1880, Nutting, 1908
Family Chunellidae	*Calibelemnon symmetricum*	HI Islands	196-1650**	Nutting, 1908, Chave and Malahoff, 1998
Family Echinoptilidae	*Echinoptilum macintoshi*	HI Islands	225-232*	Hubrecht, 1885, Nutting, 1908
Family Funiculinidae	*Funiculina* sp.	HI Islands	254-1940**	Chave and Malahoff, 1998
Family Halipteridae	*Halipterus willemoesi*	HI Islands		fide Williams
Family Kophobelemnidae	*Kophobelemnon* sp. (short stemmed)	HI Islands		Prelim. ID by Cairns, Pisces Cruise 2003
Family Pennatulidae	*Pennatula flava*	HI Islands	223-316*	Nutting, 1908
	Pennatula pallida	HI Islands	402-530*	Nutting, 1908
	Pennatula pearceyi	HI Islands	1033*	Kolliker, 1880, Nutting, 1908
	Pennatula sanguinea	HI Islands	903-1033*	Nutting, 1908
Family Protoptilidae	*Protoptilum wrighti*	HI Islands	523*	Nutting, 1908
	Protoptilum attenuatum	HI Islands	925*	Nutting, 1908
	Protoptilum studeri	HI Islands	97-421*	Nutting, 1908
Family Umbellulidae	*Umbellula carpenteri*	HI Islands	1046-2056*	Kolliker, 1880, Nutting 1908
	Umbellula gilberti	HI Islands	708-1951*	Nutting, 1908
	Umbellula jordani	HI Islands	704-2403*	Nutting, 1908
Family Virgulariidae	*Virgularia abies*	HI Islands	223*	Kolliker, 1870
	Virgularia molle	HI Islands	1265-1280*	Kolliker, 1880
Class Hydrozoa				
Order Stylasterina				
Family Stylasteridae	*Distichopora (Haplomerismos) anceps*	HI Islands	360-577**	Cairns, 1978, 2005
	Distichopora asulcata	HI Islands	293-377**	Cairns, 2005
	Stylaster griggi	HI Islands	322-583**	Cairns, 2005
	Stylaster infundibuliferus	HI Islands	521-563**	Cairns, 2005

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

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I. INTRODUCTION

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

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

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

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

II. GEOLOGICAL SETTING

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

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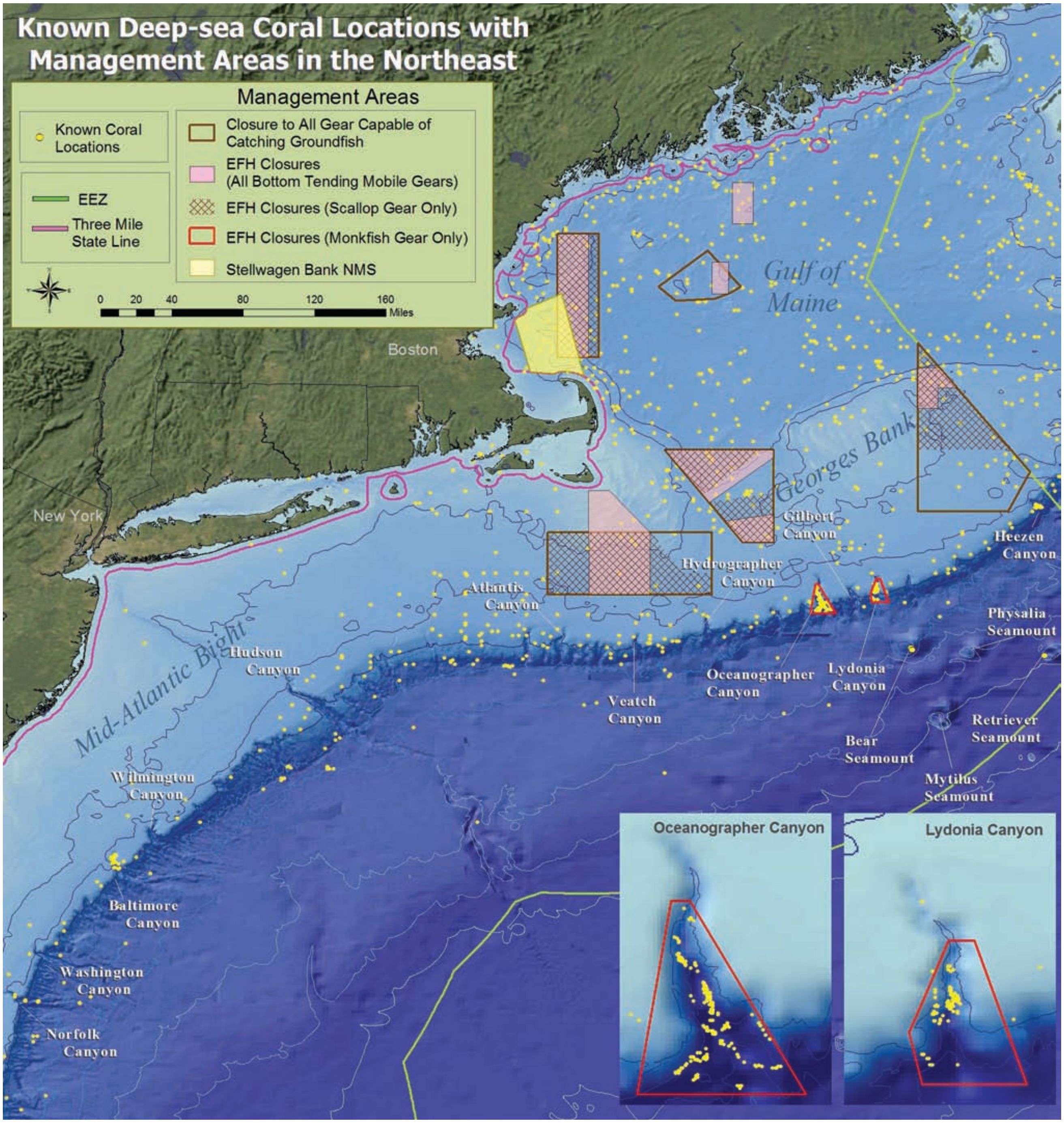


Figure 5.1 Coral Distribution - Deep coral data from the Theroux and Wigley (1998) and the Watling et al. (2003) databases represent known locations of stony, gorgonian, and true soft deep coral species from data ranging from (but not inclusive of) 1870 to the 1990s. This information does not represent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

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

Gulf of Maine

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

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

Georges Bank

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

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

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

Mid-Atlantic Bight

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

III. OCEANOGRAPHIC SETTING

Gulf of Maine

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

Georges Bank

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

Mid-Atlantic Bight

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

IV. STRUCTURE AND HABITAT-FORMING DEEP CORALS

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

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

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

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

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

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

b. *Black Corals* (Class Anthozoa, Order Antipatharia)

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

c. *Gold Corals* (Class Anthozoa, Order Zoanthidea)

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

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

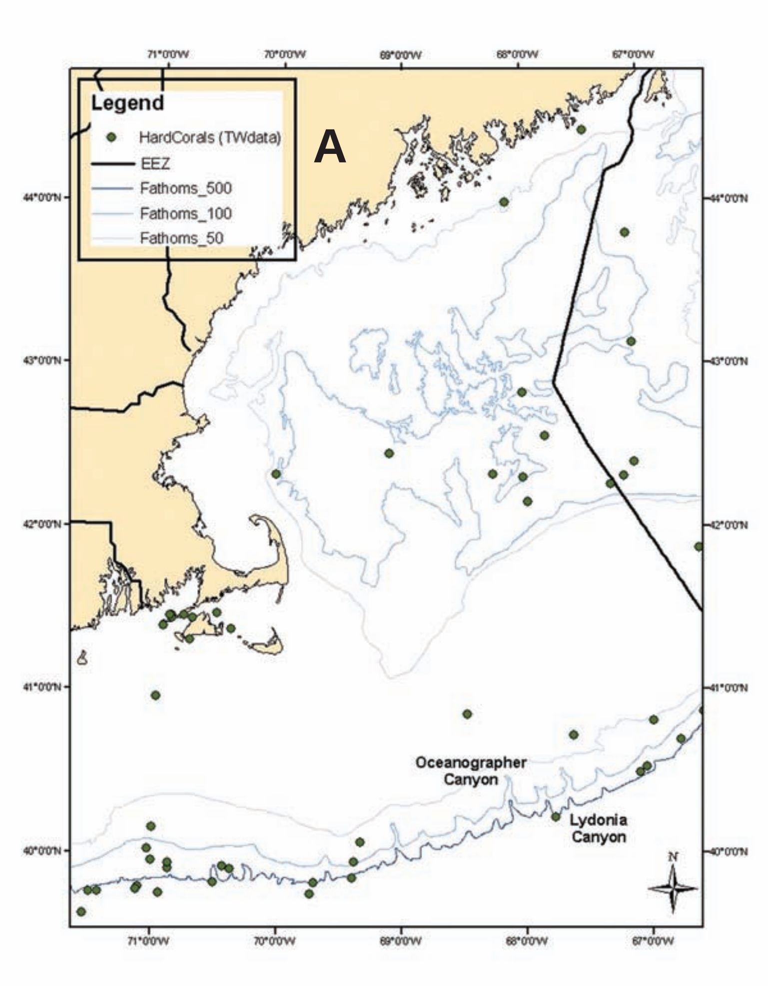
Taxa	Species
Order Gorgonacea	
Acanthogorgiidae	*Acanthogorgia armata* Verrill, 1878
Paramuriceidae	*Paramuricea grandis* Verrill, 1883
	Paramuricea placomus (Linné, 1758)
	Paramuricea n. sp.
	Swiftia casta (Verrill, 1883)
Anthothelidae	*Anthothela grandiflora* (Sars, 1856)
Paragorgiidae	*Paragorgia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

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

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

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

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



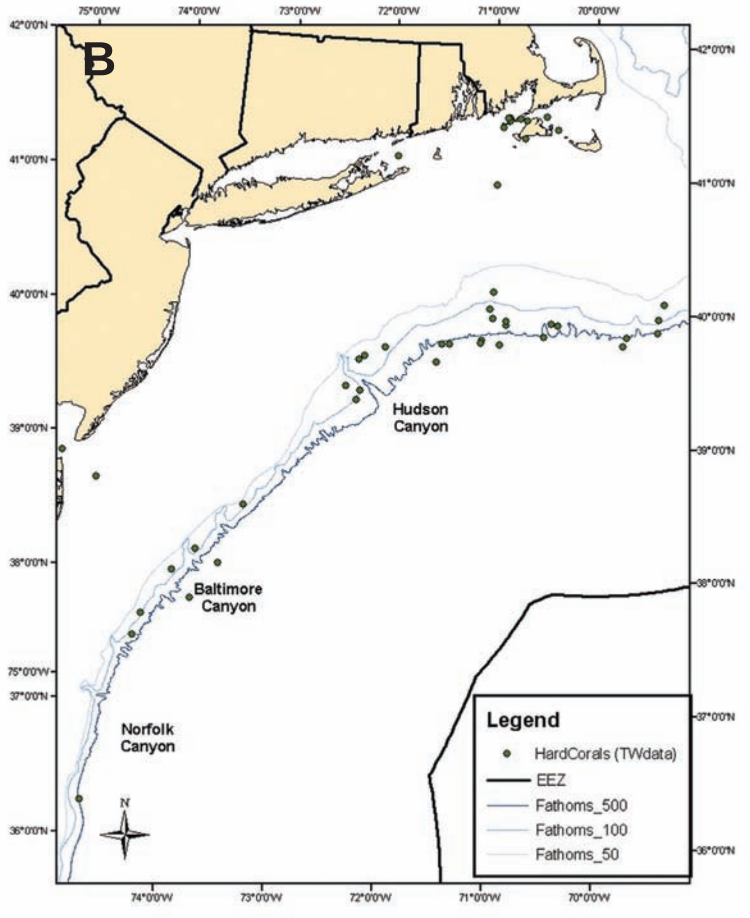


Figure 5.2 A**.** Distribution of stony or hard corals (*Astrangia, Dasmosmilia*, and *Flabellum*) in the Gulf of Maine and Georges Bank. B) Distribution of stony or hard corals (*Astrangia*, *Dasmosmilia*, and *Flabellum*) in the Mid-Atlantic. Source credit: Theroux and Wigley (1998) database.

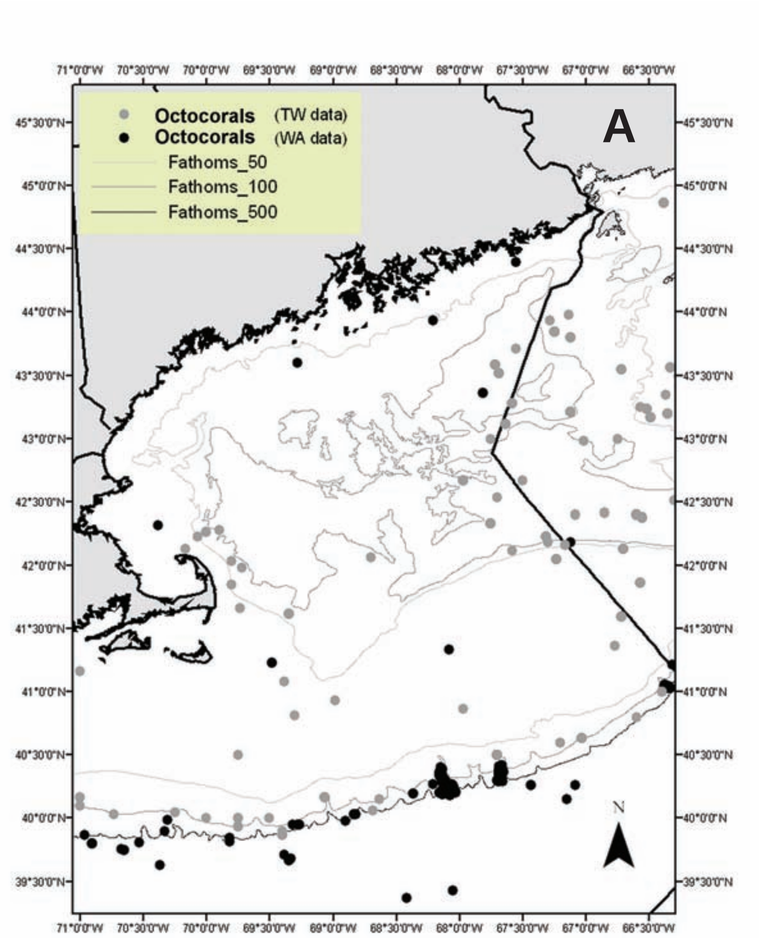
Chrysogorgiidae, Primnoidae, and Isiddae) are the best documented because of their larger sizes, as well as being most abundant in the deeper waters of the continental slope (Watling and Auster 2005). It should be noted that, for a variety of reasons, there is uncertainty about the accuracy of the identifications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

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

As stated above, the Watling et al. (2003) database obtained records of both gorgonian and true soft coral occurrences from a variety of sources, including Verrill, Deichmann (1936),Hecker and collaborators [e.g.; Hecker (1980, 1990), Hecker and Blechschmidt (1980), Hecker et al. (1980, 1983); see descriptions below], Yale Peabody museum collections, the NEFSC benthic database of identified coral taxa, and observations from recent National Undersea Research Center (NURC) field studies [for further information, see Watling and Auster (2005)]. A total of 9 species in 3 families were recorded for the northeastern U.S. shelf and slope north of Cape Hatteras (Table 5.2). Two species that were not common in the database, but apparently are very numerous in nearshore records, were the soft corals *Gersemia rubiformis* and *Alcyonium* species (Watling and Auster 2005). As with the gorgonians, it should be noted that, for a variety of reasons, there is uncertainty about the accuracy of the identifications from these various surveys (Watling and Auster 2005), so these surveys should be interpreted with caution. Soft corals have also been collected during recent expeditions to the New England and Corner Rise Seamounts (Moore et al. 2003; Watling et al. 2005, 2006).

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

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



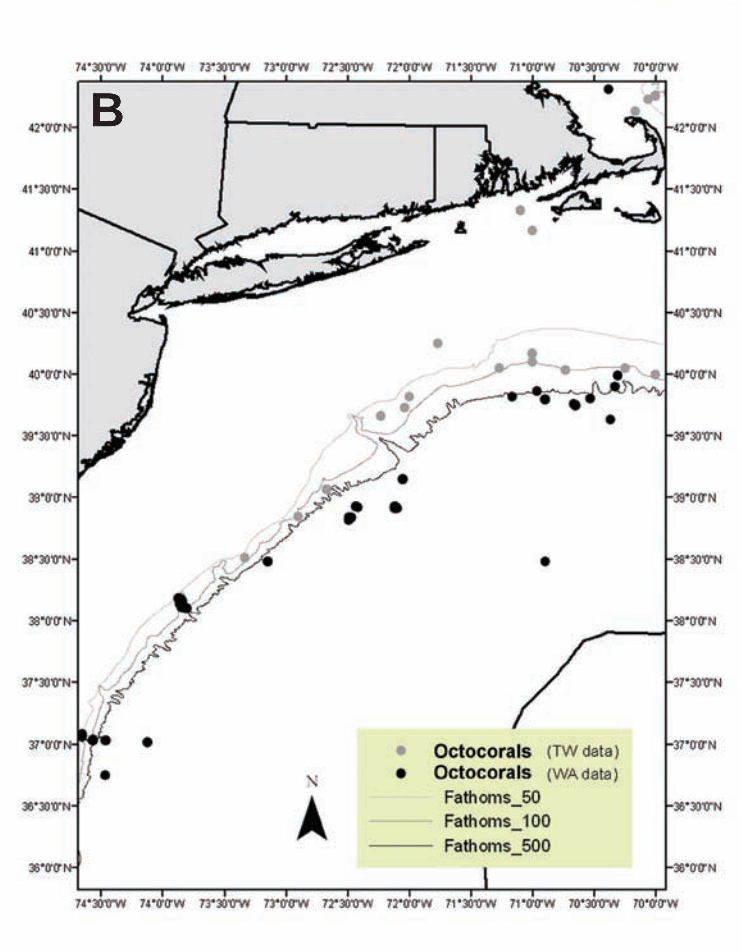
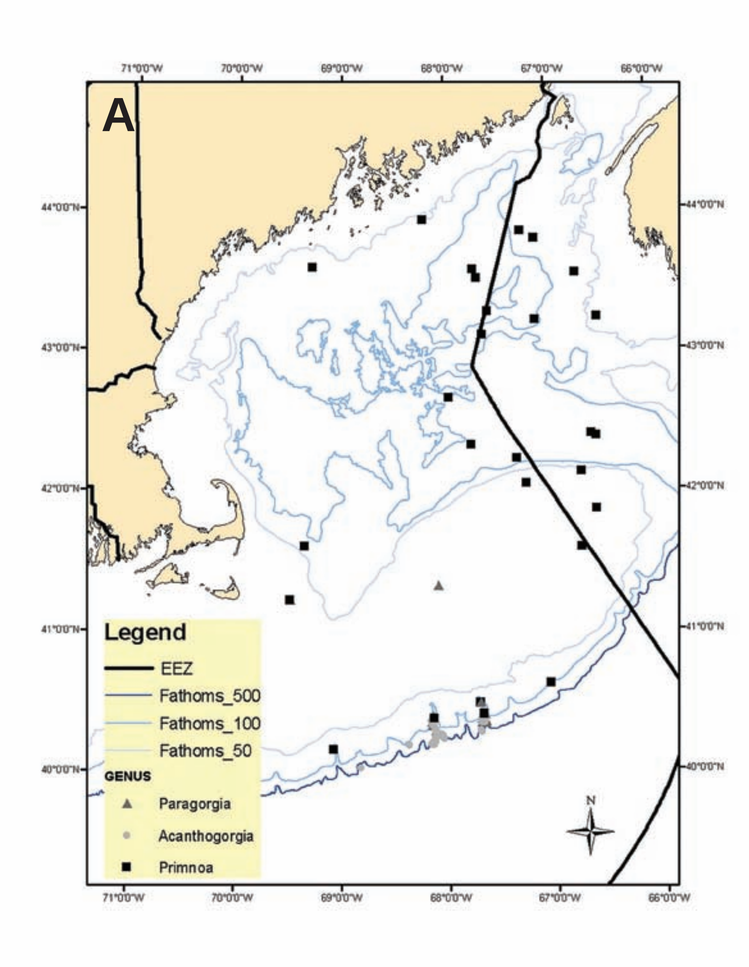


Figure 5.3 A) Distribution of gorgonians and soft corals in the Gulf of Maine and Georges Bank. B) Distribution of gorgonians and soft corals in the Mid-Atlantic. Source credits: Theroux and Wigley (1998) database, Watling et al. (2003) database.



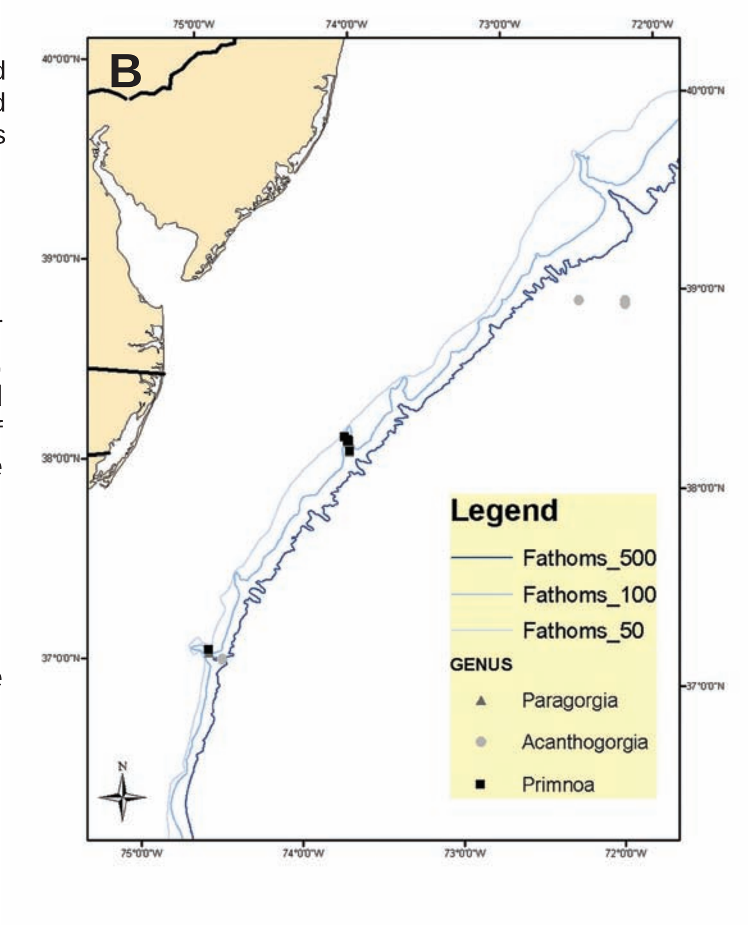


Figure 5.4 A) Distribution of the gorgonians *Acanthogorgia armata, Paragorgia arborea*, and *Primnoa resedaeformis* in the Gulf of Maine and Georges Bank. B) Distribution of the gorgonians *Acanthogorgia armata, Paragorgia arborea,* and *Primnoa resedaeformis* in the Mid-Atlantic. Source credit: Watling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

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

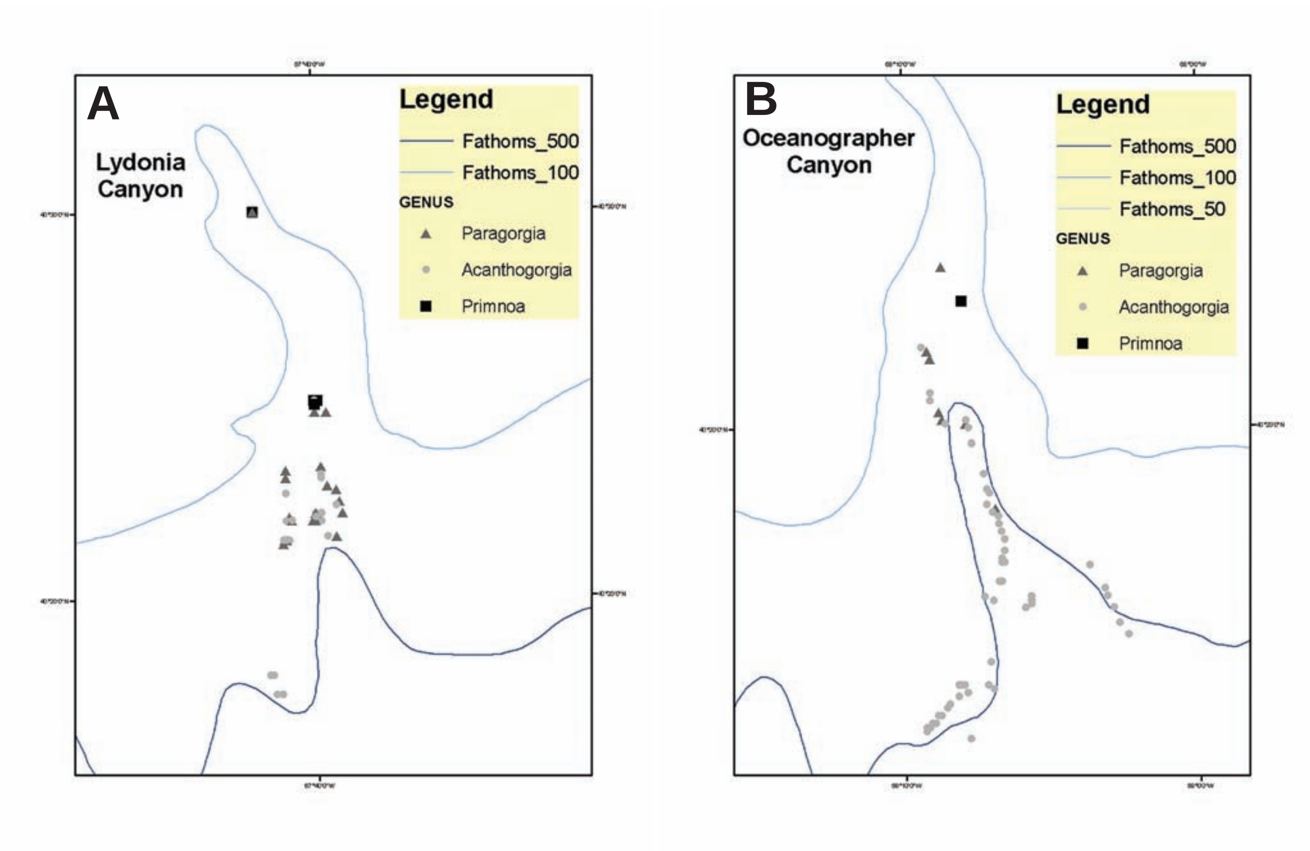
g. *Stylasterids* (Class Hydrozoa, Order Anthothecatae, Suborder Filifera, Family Stylasteridae)

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

V. SPATIAL DISTRIBUTION OF CORAL SPECIES AND HABITATS

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

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



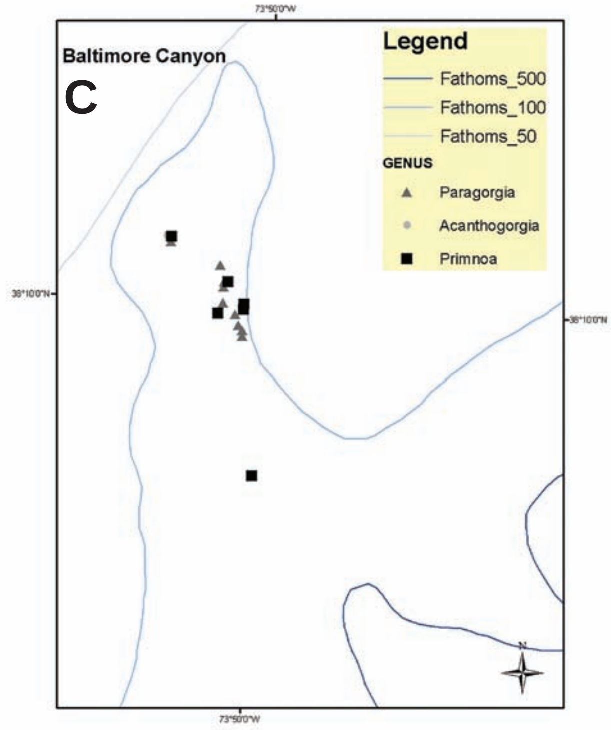


Figure 5.5 Distribution of the gorgonians *Acanthogorgia armata, Paragorgia arborea,* and *Primnoa resedaeformi*s in A) Lydonia and B) Oceanographer Canyons (Gulf of Maine) and C) Baltimore Canyon (Mid-Atlantic). Source credit: Watling et al. (2003) database.

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

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

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

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

Continental Margin/Slope and Submarine Canyons

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

Lydonia Canyon

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

Oceanographer Canyon

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

Baltimore Canyon

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

Other Canyons

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

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

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

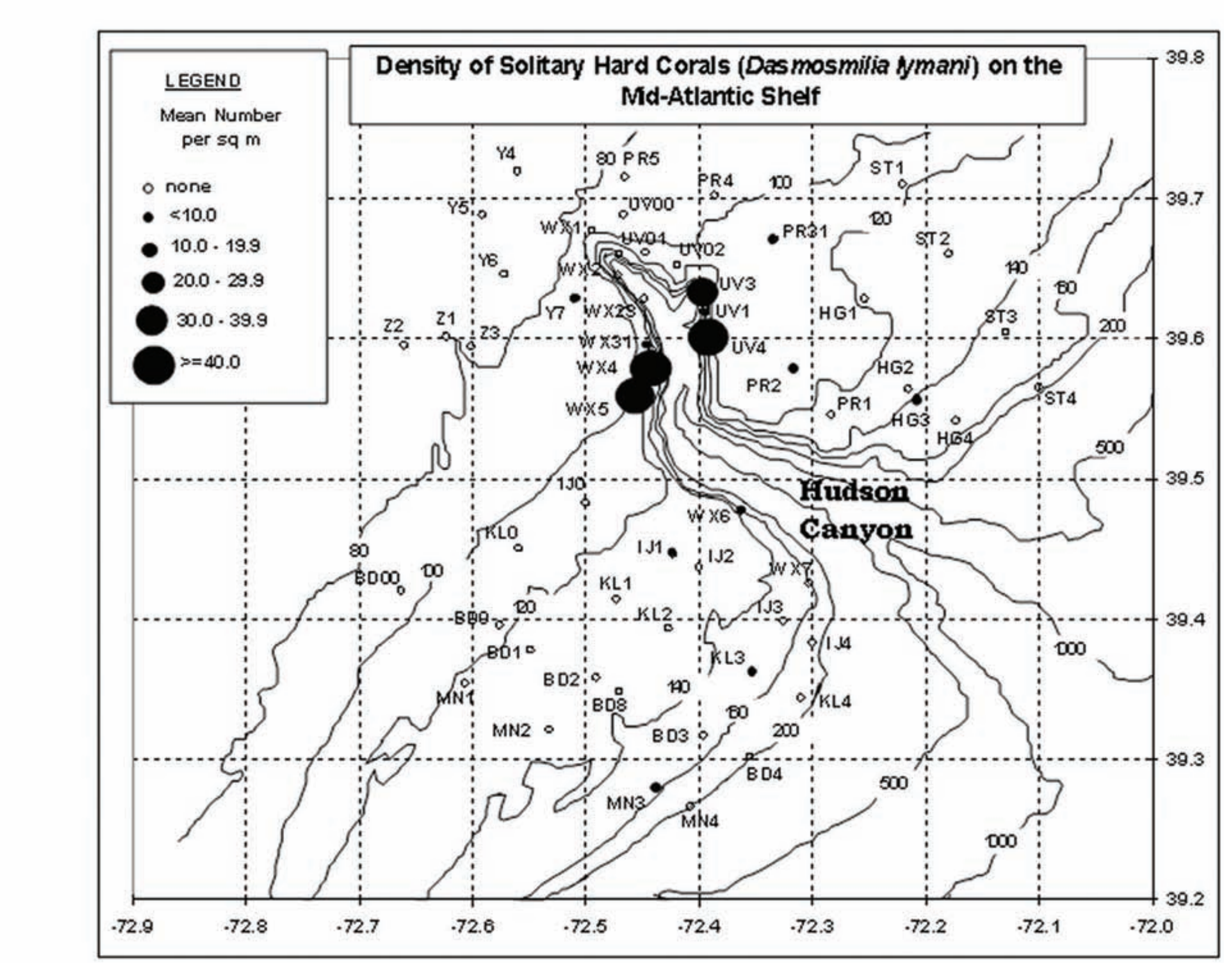


Figure 5.6. Distribution and approximate densities (polyps per square meter) of the solitary stony coral *Dasmosmilia lymani* in samples from the Mid-Atlantic shelf around Hudson Canyon (Guida, unpublished data). Data obtained from still photos and trawl samples taken during October and November 2001,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

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

Other Areas of the Continental Slope

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

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

The New England Seamounts

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

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

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

VI. SPECIES ASSOCIATIONS WITH DEEP CORAL COMMUNITIES

Commercial Fisheries Species

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

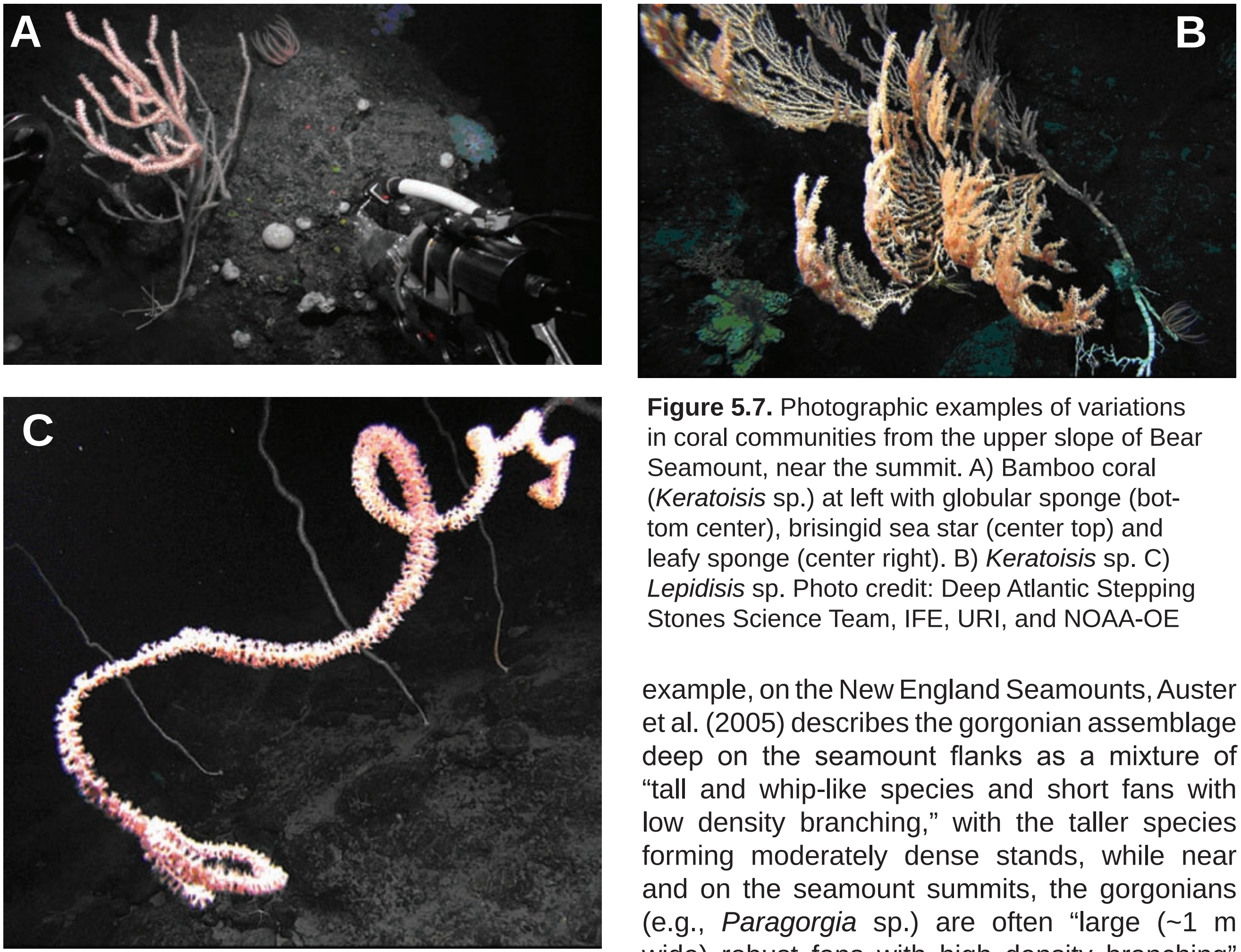


Figure 5.7. Photographic examples of variations in coral communities from the upper slope of Bear Seamount, near the summit. A) Bamboo coral (*Keratoisis* sp.) at left with globular sponge (bottom center), brisingid sea star (center top) and leafy sponge (center right). B) *Keratoisis* sp. C) *Lepidisis*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

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

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

Invertebrates

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

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

VII. STRESSORS ON DEEP CORAL COMMUNITIES

Fishing Effects

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

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

Effects of other human activities

Invasive Species

Little is known about any existing or potential interactions between deep corals and invasive species. One invasive species that may be a threat in the northeast is the colonial tunicate (“sea squirt”), *Didemnum* sp. A. (Bullard et al. 2007). It is currently undergoing a massive population explosion and major range expansion and has become a dominant member of many subtidal communities on both coasts of North America. It was recently discovered on the northern edge of Georges Bank, and is found on hard gravel substrates, including, pebbles, cobbles, and boulders, and overgrows sessile and quasi-mobile epifauna (sponges, anemones, scallops, etc.). The species can occur on immobile sand substrates, but is not known to occur on mobile sand or mud substrate. On Georges Bank, *Didemnum* sp. A covers 50–90% of the substrate at numerous sites over a 230 km^2 area to a depth of 45-60 m (Bullard et al. 2007). *Didemnum* sp. A has the potential to spread rapidly by budding, and fragmentation of the mats could promote the rapid spread of the species. There are no known predators at this time, although there have been some observations of possible seastar predation (Bullard et al. 2007).

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

Other

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

VIII. MANAGEMENT OF FISHERY RESOURCES AND HABITATS

Mapping and Research

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

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

Fishery Management Councils

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

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

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

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

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

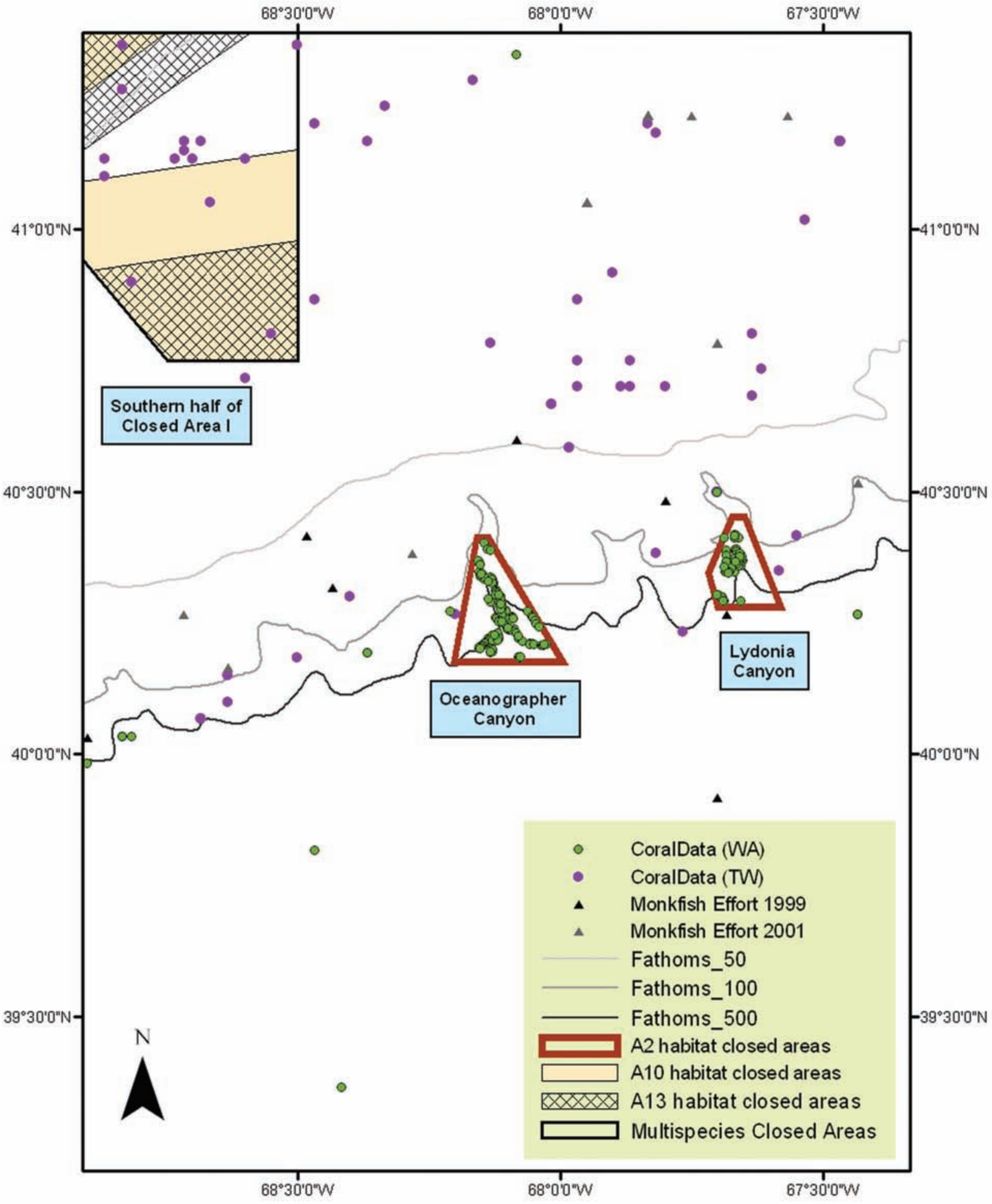

Figure 5.8. The Oceanographer and Lydonia Canyon Essential Fish Habitat closed areas, under Amendment 2 to the Monkfish Fishery Management Plan; locations of known alcyonaceans from the Theroux and Wigley (1998) and Watling et al. (2003) databases; and, 1999 and 2001 directed monkfish otter trawl trips.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

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

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

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

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

IX. REGIONAL PRIORITIES TO UNDERSTAND AND CONSERVE DEEP CORAL COMMUNITIES

Mapping

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

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

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

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

Research

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

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

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

X. CONCLUSION

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

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

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

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

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

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

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

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

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

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

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

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

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

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

STATE OF DEEP CORAL ECOSYSTEMS IN THE U.S. SOUTHEAST REGION:

CAPE HATTERAS TO SOUTHEASTERN FLORIDA

Steve W. Ross[1] and Martha S. Nizinski[2]

I. INTRODUCTION

Unique and productive deep coral habitats are found off the southeastern United States. This region may have the best developed, most extensive (Hain and Corcoran 2004) deep coral areas in U.S. waters. These deep reef systems have been largely ignored until recently, and this is partly due to their rugged bottom topography and the fact that they are usually overlain by extreme currents (i.e., Gulf Stream). Deep coral ecosystems face increasing threats world wide (Morgan et al. 2006; Roberts et al. 2006). Fisheries are expanding rapidly into deeper regions (Koslow et al. 2000; Roberts 2002), and hydrocarbon exploration and development are now also exploiting these depths. Two general deep coral habitats are reviewed for the southeastern U.S.: one is located along the shelf edge off east-central Florida, formed by the stony coral *Oculina varicosa*, and the second includes deeper water slope habitats dominated by the hard coral *Lophelia pertusa* (plus other corals and sponges) occurring off North Carolina and on the Blake Plateau off South Carolina through the Straits of Florida.

Deep coral habitats have been poorly studied, particularly in the western Atlantic. With the exception of the *Oculina* banks, references on deep corals off the southeastern U.S. are largely geological with a few biotic observations, mostly on invertebrates (Reed 2002a, 2002b; references in Sedberry 2001; Reed et al. 2006). Studies elsewhere revealed that deep reefs harbor extensive, species-rich invertebrate populations (Jensen and Frederiksen 1992; Rogers 1999; Buhl-Mortensen and Mortensen 2004). Fish studies related to the deep coral banks are rare. Our investigations of deep coral systems off the southeastern U.S. have revealed that many species of fishes (Ross and Quattrini 2007) and invertebrates are closely associated with this unique deep-reef habitat. Yet, it is unclear whether the deep coral habitat is essential to selected fishes or invertebrates or whether they occupy it opportunistically (see conflicting views in Auster 2005; Costello et al. 2005; Ross and Quattrini 2007).

We review the deep coral ecosystems off the southeastern U.S. Deep coral research to date, coral distributions, associated faunal assemblages, threats to the corals, and management strategies in the U.S. Exclusive Economic Zone (EEZ) are briefly summarized. This chapter covers the region from Cape Hatteras, NC, to Key Biscayne, FL, and a depth range of 60 to about 5000 m (deeper depths vary with EEZ boundary). We emphasize corals inhabiting waters deeper than 200 m, which is the bathymetric range where most of the deep corals in this region occur; the Florida *Oculina* reefs (60-100 m) are an exception.

History of Deep Coral Research off the Southeastern U.S.

Oculina Banks (<150 m)

Large reefs formed by *Oculina varicosa* are restricted in distribution to the shelf edge off east-central Florida. Although *O. varicosa* forms substantial structures, the reefs were heavily fished, and are concentrated in shallower waters (60-120 m) than other deep corals (see below), these extensive reefs were not described until the 1960s (see reviews in Reed 2002a,

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2002b; Reed et al. 2005). The first publication mentioning these corals along the outer shelf off Florida reported results from seismic transects, dredging, and drop cameras (Macintyre and Milliman 1970). However, commercial fishermen and Florida scientists apparently knew of these reefs earlier (Reed et al. 2005). Macintyre and Milliman (1970) noted *Oculina* clumps and coral debris along the shelf break from northern Florida southward and especially from Cape Canaveral to Palm Beach where ridges in 70-90 m were usually capped with *Oculina*. Surveys of these reefs, using manned submersibles, began in the 1970s (Avent et al. 1977). Since then, reef monitoring, utilizing submersibles and ROVs, has continued intermittently (Reed et al. 2005). Additionally, side-scan sonar surveys were conducted, and multibeam mapping is currently ongoing on these coral banks (Reed et al. 2005; A.N. Shepard, NURC, unpublished data). A variety of studies have documented coral growth, distributions, and upwelling effects on coral growth (Reed 1980, 1981, 1983), invertebrate communities associated with these reefs (Reed et al. 1982; Reed and Mikkelsen 1987), *Oculina* reproduction (Brooke and Young 2003, 2005), and fishes associated with the *Oculina* banks (Reed and Gilmore 1981; Gilmore and Jones 1992; Koenig et al. 2000, 2005; Reed et al. 2006).

These reefs were heavily fished during previous decades and incurred much damage and reduction in reef size due to impacts of fishing gear. Research continues, particularly in the zones protected by the South Atlantic Fishery Management Council (SAFMC). Funding is lacking, but habitat mapping, restoration, and monitoring are high priorities.

Deep-sea slope corals (>250 m)

Historically, deep coral research off the southeastern U.S. was temporally and spatially sporadic. Until recently deep coral research was often a by-product of non-coral projects.

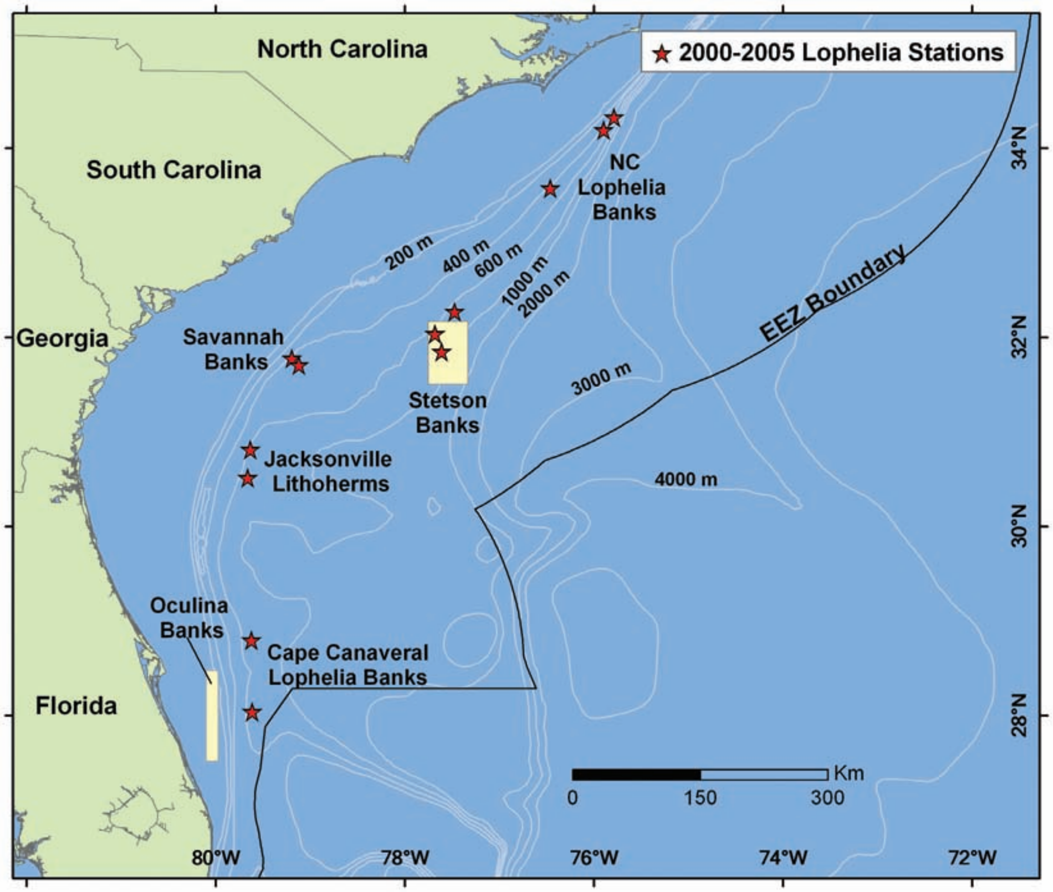


Figure 6.1. Southeastern United States regional report area, indicating general areas of *Oculina varicosa* reefs and the deeper coral (*Lophelia* mostly) habitats sampled by Ross et al. from 2000-2005 (red stars). The Stetson Bank (white box) is described in the text. Note that these areas do not represent all sites where deep (> 200 m) corals occur nor all sites visited by other researchers. See Reed et al. (2005, 2006) and Partyka et al. (in press) for additional deep coral sites in this region.

The major studies that documented deep corals in the area are briefly reviewed (in roughly chronological order); this review is not intended to be inclusive.

The first report of deep corals from the Blake Plateau resulted from the 1880 collections of the steamer *Blake* (Agassiz 1888). These collections were poorly documented, and the bottom on the Blake Plateau was characterized as being hard and barren (Agassiz 1888). The research vessel *Albatross* collected corals on the Blake Plateau in 1886 using beam trawls and tangles. Some *Lophelia* specimens in those collections were deposited in the National Museum of Natural History (Smithsonian Institution), but were otherwise poorly documented. Squires (1959) noted several scleractinian species collected by dredge in 1954 off Palm Beach, FL in 686 m. Cairns (1979) re-examined Squires' coral collections and corrected identifications, resulting in the following species: *Lophelia pertusa*, *Crispatotrochus* (=*Caryophyllia*) *squiresi*, *Enallopsammia profunda*, and *Tethocyathus variabilis*.

An area of very rough topography containing deep corals was discovered on the Blake Plateau off South Carolina, resulting from surveys by depth sounder in the mid-1950's (Stetson et al. 1962). However, confirmation that these features supported extensive coral habitat was not achieved until they were dredged and photographed in 1961 (Stetson 1961). Stetson et al. (1962) gave the first detailed accounting of this area now called the "Stetson Banks" (Figure 6.1), confirming the occurrence of two major species of hard corals, *Lophelia pertusa* and *Enallopsammia* (=*Dendrophyllia*) *profunda*. They also reported species of *Bathypsammia*, *Caryophyllia*, and *Balanophyllia* as well as abundant alcyonarians. Additional details from the 1961 cruise, including locations of hundreds of coral mounds, were described by Stetson et al. (1969).

Through the 1960s a series of geological papers based largely on precision echosounding data noted that numerous mounds, termed coral mounds, existed on the Blake Plateau and the Florida-Hatteras slope (e.g., Uchupi and Tagg 1966; Uchupi 1967; Zarudzki and Uchupi 1968). Pratt (1968) presented one photograph of *Lophelia* corals on the Blake Plateau ("Stetson Banks"). In 1967, five manned submersible dives using the DSRV *Alvin* were made in an area west of the "Stetson Banks." Two of these dives confirmed the occurrence of *Enallopsammia* (=*Dendrophyllia*) and *Lophelia* in the region (Milliman et al. 1967). Additionally, coral topped mounds (to 15 m high) were described from along the slope off Biscayne Bay, FL (around 700-825 m) (Neumann and Ball 1970), based on 1967 *Alvin* dives.

Although corals were discovered on the Blake Plateau in the 1880s and investigated in the late 1950s and early 1960s (Squires 1959; Stetson et al. 1962), such corals were not reported off North Carolina until the late 1960s. Based on seismic profiling, Uchupi (1967) first noted the occurrence of a coral mound off Cape Lookout, NC, which may be the same area illustrated (figure caption without comment) by Rowe and Menzies (1968). Rowe and Menzies (1969) later suggested that *Lophelia* sp. occurred off the Carolinas in "discontinuous banks" along the 450 m contour, but gave no specific data. Menzies et al. (1973) vaguely referenced a "Lophohelia" bank off Cape Lookout, repeating a figure in Rowe and Menzies (1969), and presented a bottom photograph of a reef in 458 m. Cairns (1979) plotted a locality for *Lophelia* off Cape Lookout. Aside from Uchupi's (1967) observations, the above North Carolina records mostly originated from a training cruise of the R/V *Eastward* (E-25-66, I.E. Gray, chief scientist) during which a coral bank was photographed by drop camera (station E-4937, 475 m) and dredged (E-4933, 425 m) on 30 June 1966. The Menzies et al. (1973, Figure 4-4 B) photograph is from that cruise. This coral bank was discovered accidentally (independently of Uchupi 1967) as a result of constantly running the *Eastward*'s depth sounder (L.R. McCloskey and G.T. Rowe, pers. comm.). There were a few other short *Eastward* cruises to this area off Cape Lookout directed by Menzies, Rowe, Gray, or McCloskey, but no coral data were published. This *Eastward* station area was trawled and surveyed by sonar in May 1983 (R/V *Delaware II* cruise, S.W. Ross, chief scientist), but no hard bottom or coral were found. Coral mounds were located in this vicinity during an undersea survey using the Navy's *NR-1* nuclear research submersible (15-18 Nov 1993, K.J. Sulak and S.W. Ross, unpublished data). Three major coral areas have been located and studied off North Carolina (Ross and Quattrini 2007; Partyka et al. in press), and other mounds may exist. All three areas off North Carolina were surveyed by multibeam sonar during October 2006 (Ross and Nizinski, unpublished data), revealing many mounds that had not been known. The slope off Cape Lookout appears to be the northern extent of deep corals in the southeast region.

Over the next three decades most studies around southeastern U.S. deep coral areas continued to be geological and generally not directed toward corals. Exceptions include Cairns (1979, 1981, 2000, 2001a), who listed ranges for deep sea Scleractinia and azooxanthellate corals in this region, relying mostly on museum records. Neumann et al. (1977) described hard carbonate mounds in the eastern Straits of Florida off Little Bahama Bank that were covered in various corals (*Lophelia* and *Enallopsammia*) and other invertebrates. They coined the term “lithoherms” for these structures. In this same area in 1982, and also using *Alvin*, researchers collected and aged several “coral” species, indicating that these animals lived from several hundred up to 1800 years (Griffin and Druffel 1989; Druffel et al. 1990, 1995). These corals have annual rings that contain a wealth of information about past climates, ocean productivity, and contamination. This significant discovery has vast implications for the scientific value of deep corals as proxies for climate change and recorders of environmental histories (Williams B et al. 2006; Williams et al. in press). Ayers and Pilkey (1981) documented several coral banks, collected corals, and dated some coral samples during a study of sediments of the Florida-Hatteras slope and inner Blake Plateau. Depending on location in a core, their dead coral samples ranged in age from 5,000 to 44,000 years old. They dated a living specimen at 680 years old, but suggested that this age probably reflected the age of the carbon pool in the surrounding water. Pinet et al. (1981) also mapped coral banks overlapping the same area as Ayers and Pilkey (1981). Blake et al. (1987) briefly mentioned the presence of some soft and hard corals on the Blake Plateau. Many deep-reef locations were indicated by the U.S. Geological Survey sidescan sonar mapping (cruises in 1987) of the continental slope (EEZ-SCAN 87 Scientific Staff 1991); however, habitats were not verified in this large scale geological survey. Perhaps the first study to document the invertebrate community associated with deep-coral habitat in this region reviewed biozonation of lithoherms in the northeastern Straits of Florida (Messing et al. 1990). Genin et al. (1992) noted that sponges and gorgonians were common along the outer Blake escarpment (2624-4016 m) based on observations made during *Alvin* dives in 1980. They suggested that these communities were unusually dense for sites lacking sediment. Popenoe (1994) discussed the distribution and formation of coral mounds on the Blake Plateau and presented a few bottom photographs. Paull et al. (2000) surveyed deep-coral habitats off the Florida-Georgia border, dated parts of the structures, and suggested that such habitat was very common. Their dating indicated that some mounds may range from 18,000 to 33,000 years old. Popenoe and Manheim (2001) extensively reviewed geology, history, and habitats of the Blake Plateau around the area of the Charleston Bump, discussing various parameters that may control coral mound formation. Wenner and Barans (2001) described benthic habitats of the Charleston Bump area and noted some of the invertebrates and fishes occurring with deep corals. George (2002) discussed a coral habitat, dominated by *Bathypsammia tintinnabulum*, southeast of Cape Fear, NC (“Agassiz Coral Hills”) in 650-750 m. Apparently, the *B. tintinnabulum* used by Emilini et al. (1978) came from the collections noted by George (2002). A multibeam sonar survey of this site in 2006 (Ross and Nizinski, unpublished data) revealed a flat bottom with no suggestion of coral mounds. Reed (2002a, 2002b; Reed et al. 2006) described several large areas of deep corals on the Blake Plateau and listed some of the fauna observed. As part of a SEAMAP bottom mapping project, data and reports to be examined for evidence of deep corals in this area were summarized by Arendt et al. (2003). This project was completed in 2006 and will be incorporated into the South Atlantic Fishery Management Council’s internet display.

Beginning in 2000 and continuing through the present, deep coral (or related habitat) research in the southeastern U.S. was stimulated by funding of studies through the NOAA Office of Ocean Exploration (see http://oceanexplorer.noaa.gov/explorations) and supplemented by other sources. Teams lead by Principal Investigators S.D. Brooke, S.A. Pomponi, S.W. Ross, and G.R. Sedberry explored deep-coral banks throughout the southeast, mapping habitats, cataloging fauna, and conducting basic biological studies. A multi-investigator effort to create detailed habitat classifications (Southeastern U.S. Deep-Sea Corals initiative, SEADESC) from past submersible dives in the area is underway (Partyka et al. in press). Future publications are forthcoming from the considerable data collected by these efforts.

II. GEOLOGICAL SETTING

Geology of the southeastern U.S. continental shelf, slope and rise has been well studied (see reviews in Pratt 1968; Avent et al. 1977; Schlee et al. 1979; Dillon and Popenoe 1988; Popenoe and Manheim 2001). The southeastern U.S. shelf and slope have been classified as a carbonate sedimentary province whose sediments are largely of terrigenous origin (Pratt 1968). The shelf edge (<200 m), including the region of the Florida *Oculina* banks, is marked by numerous topographic prominences of various origins (Macintyre and Milliman 1970; Avent et al. 1977; Thompson and Gilliland 1980), and these provide substrate for attachment of a largely subtropical fauna (including corals). Unlike the Middle Atlantic Bight and Gulf of Mexico, major canyons that cut across the slope are missing in the southeast region. From central North Carolina northward the slope is particularly steep and characterized by a slump topography (Pratt 1968). The Gulf Stream is and has been (since the early Tertiary) a dominant force shaping the bottom topology of the southeast region, and has scoured a steep channel along most of its length, often exposing hard substrates and creating a rugged topography.

The continental slope through much of the southeastern U.S. (central North Carolina to the Straits of Florida) is atypical of most U.S. slope configurations. It is unusually wide and is dominated by the Blake Plateau, a broad depositional feature formed by the Gulf Stream (400-1250 m depths, Popenoe and Manheim 2001). The Blake Plateau exhibits two major topographic breaks, one on its western margin, the Florida-Hatteras Slope (shelf to about 600 m), and the Blake Escarpment (descending to about 4800 m) on the southeastern margin (south of the Blake Spur). The eastern slope of the Blake Plateau north of the Blake Spur exhibits a more typical, less steep profile and grades into the Blake Ridge and Carolina Rise (Markl et al. 1970). The Blake Ridge contains extensive gas hydrate deposits and the only known methane seep community in this area (Borowski et al. 1997; van Dover et al. 2003). The Blake Plateau is an extension of the Bahamian carbonate province, with carbonates being contributed by pteropod and *Globigerina* material as well as corals and other invertebrates (Pratt and Heezen 1964). Numerous scarps, mounds, plateaus, and depressions occur in this region, and deep corals are common along the edges of the scarps and ridges and on the mounds (Stetson et al. 1962; Pratt and Heezen 1964). One dominant topographic structure of the Blake Plateau is the Charleston Bump, which presents a partial barrier to Gulf Stream flow, deflects the Gulf Stream seaward, and is heavily scoured by this current, exposing hard substrates (Popenoe and Manheim 2001). Manganese pavements and nodules are abundant over the plateau (Brundage 1972). The western side of the Blake Plateau particularly has been heavily eroded (mostly during the Pleistocene) by the Gulf Stream, exposing numerous depressions, Cretaceous to Miocene aged hard substrata, and mounds (Uchupi 1967).

The southern part of this region (to off Key Biscayne, southern border for this report) is mostly within the Straits of Florida. This area is swept by the Florida current (part of the Gulf Stream system), and the bottom exhibits closely spaced valleys, ridges, mounds and lithoherms that are part of a carbonate platform (Malloy and Hurley 1970; Neumann et al. 1977). The northwestern side of the Straits of Florida is bordered by the Miami Terrace, a carbonate platform in 200 to 400 m that exhibits varied hardbottom topography (Reed et al. 2005). A variety of deep corals occur on hard substrates of the Straits of Florida (Neumann et al. 1977; Messing et al. 1990; Reed et al. 2005, 2006).

III. OCEANOGRAPHIC SETTING

The dominant oceanographic feature that shapes much of the geology and biology of the outer shelf and slope off the southeastern U.S. is the Gulf Stream current (or Florida Current). This well studied system influences bottom conditions even at continental slope depths by cutting off shelf sediment delivery to offshore areas (mostly between northern Florida to southern North Carolina), transporting sediments northward, and facilitating high current speeds (up to

2.5 kn, 125 cm/s) on the bottom (Pratt 1968; Popenoe and Manheim 2001). The jet-like flow of the Gulf Stream has a surface width around 80-150 km with a depth of 800-1200 m, fastest current speeds being near the surface center (Bane et al. 2001). The Gulf Stream provides a seasonally stable temperature (generally >27° C) and salinity (generally >36 psu) regime for the outer shelf and slope. This current transports an increasingly massive volume of water as it moves northward (Bane et al. 2001). Inshore of the Gulf Stream (ca. <40 m depth) the physics of the continental shelf water column is dominated by tides, meteorology (e.g., winds, rainfall), and gravity waves (Pietrafesa 1983; Mathews and Pashuk 1986).

This complex current meanders (influenced in part by bottom topography) and produces eddies that spin away from the main current (Atkinson et al. 1985; Bane et al. 2001). As the Gulf Stream is deflected offshore away from the shelf edge, particularly off South Carolina (by the Charleston Bump) and off central North Carolina, nitrogen-rich deeper water upwells onto the outer shelf, leading to localized areas of enhanced carbon production (Atkinson et al. 1982; Lee et al. 1991). Much of this carbon is subsequently transported offshore (Lee et al. 1991). As the Gulf Stream has varied in position since the Pleistocene, it may alternately uncover deep bottom substrata suitable for deep coral settlement or facilitate burial of coral mounds (Zarudzki and Uchupi 1968).

Being on the shelf edge, the Florida *Oculina* banks experience more temperate conditions. Bottom water temperatures can vary widely over short time scales (days to weeks) and on some banks can range from about 7° to 27° C (Avent et al. 1977; Reed 1981), being alternately washed by warm Gulf Stream or inshore waters and deeper, cold waters. The colder conditions are usually caused by upwelling, which also provides an increased amount of nutrients (Reed 1983). Bottom visibility on these banks is generally low, current speeds can be variable (sometimes >50 cm sec^{-1}), and sedimentation rates moderately high (15-78 mg cm^{-2} day^{-1}) (Reed 2002b).

While the surface and upper water column oceanography beyond the shelf edge are fairly well studied, bottom conditions over most of the slope are not well known. Long term data are particularly lacking. High current speeds have been reported (see above), but currents can vary from near zero to >50 cm sec^{-1} over short time scales (pers. obs.). Bottom currents are more complex around coral mound or rocky features and are accelerated through valleys and over the tops of mounds/ridges (pers. obs.). Recent multibeam sonar mapping suggested that long term current scouring helped shape deep-coral mounds off North Carolina, but that conditions were different at the deeper Stetson area habitats (Ross and Nizinski, unpublished data). Bottom temperatures around southeastern U.S. deep coral habitats (370-780 m) ranged from 5.4° to 12.3° C and salinities varied little from 35 psu (Ross and Quattrini 2007). Similar environmental data from southeastern U.S. deep coral habitats were reported by Reed et al. (2006).

IV. STRUCTURE-FORMING DEEP CORALS OF THE SOUTHEASTERN U.S.

The southeastern U.S. slope area, including the slope off the Florida Keys, has a unique assemblage of deep-water scleractinians (Cairns and Chapman 2001). The warm temperate assemblage identified by Cairns and Chapman (2001), encompassing nearly the same geographic range as that covered here, consists of about 62 species, four of which are endemic to the region. This group of corals was characterized by many free-living species, few species living deeper than 1000 m, and many species with amphi-Atlantic distributions. For the southeastern U.S., in areas deeper than 200 m, we report a similar assemblage, consisting of 57 species of scleractinians (including 47 solitary and ten colonial structure-forming corals), four antipatharians, one zoanthid, 44 octocorals, one pennatulid, and seven stylasterids (Appendix 6.1). Thus, the region contains at least 114 species of deep corals (Classes Hydrozoa and Anthozoa). We note, however, that this list is conservative, and we expect that more species will be discovered in the region as exploration and sampling increase. Since solitary corals do not form reefs and are poorly known, we do not treat them in detail. Below we discuss the major structure-forming corals (Appendix 6.1) that most contribute to reef-like habitats in the southeastern U.S.

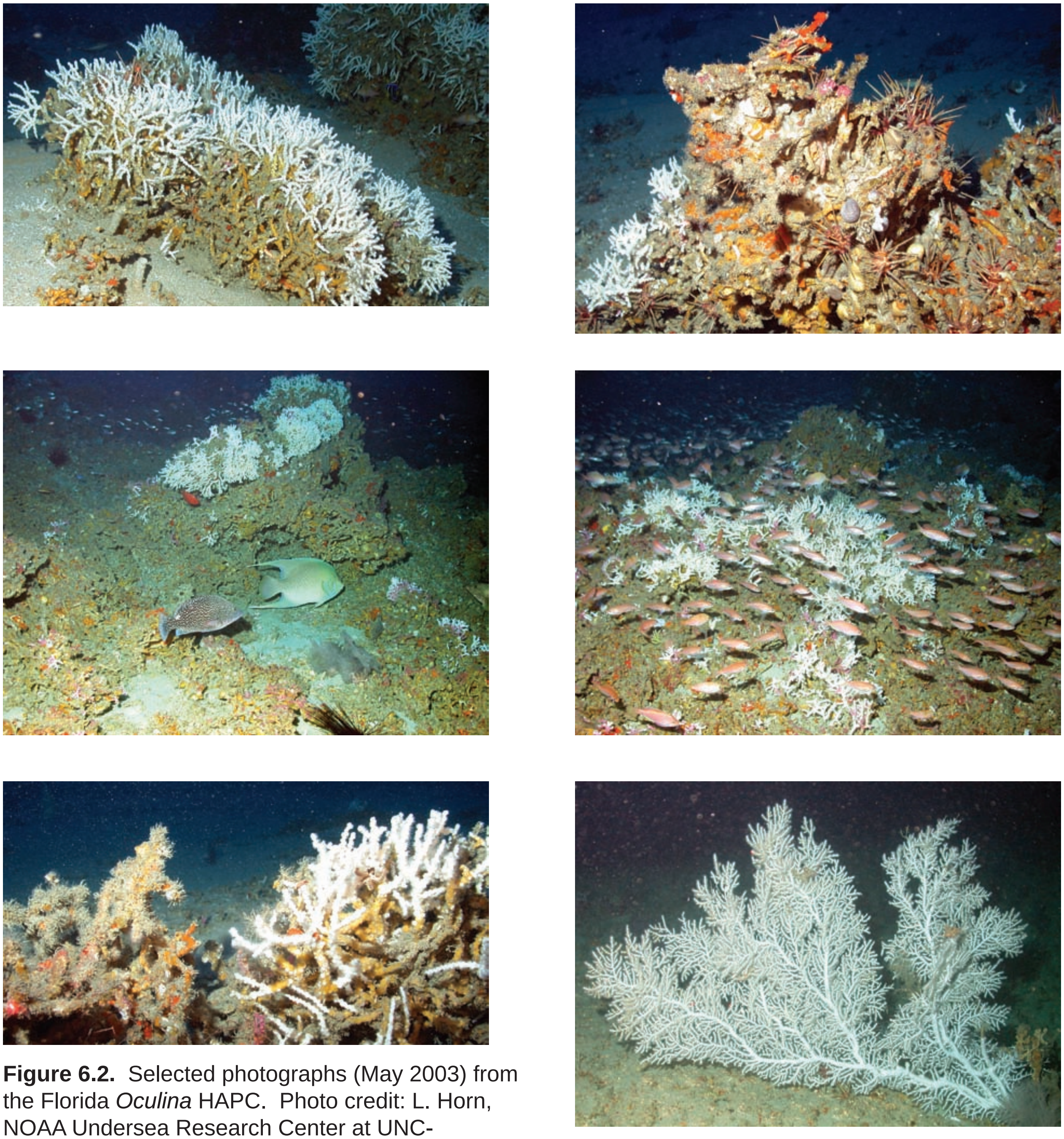


Figure 6.2. Selected photographs (May 2003) from the Florida *Oculina* HAPC. Photo credit: L. Horn, NOAA Undersea Research Center at UNC-Wilmington.

We hypothesize that high profile deep-coral reefs concentrate biota and enhance local productivity in ways similar to seamounts (Rogers 1994; Koslow 1997). The ridges and reef mounds, some rising over 100 m from open substrata, accelerate bottom currents which favors attached filter-feeding invertebrates and other biota. Thus, the growing reef alters the physics of the water column, enhancing the environment for continued coral growth and faunal recruitment (Genin et al. 1986).

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

The dominant structure-forming coral on the southeastern U.S. outer shelf (<200 m) is *Oculina varicosa* (ivory tree coral). Although it occurs from Bermuda and North Carolina south through the Gulf of Mexico and the Caribbean in 2-152 m depths, this coral only forms large reefs off east-central Florida, 27^{o} 32' N to 28^{o} 59' N, in 70-100 m (Figure 6.1; Reed 2002b). The shallow water form of *Oculina* may have symbiotic zooxanthellae, but the deeper form does not.

The deeper reefs are almost monotypic mounds and ridges which exhibit a vertical profile of 3-35 m (Avent et al. 1977; Reed 2002b). Superficially, these structures (Figure 6.2) resemble the deep reefs formed by *Lophelia pertusa*. Despite cool temperatures, the shelf edge *Oculina* exhibit rapid growth, probably facilitated by regular upwellings of nutrient rich water (Reed 1983).

Lophelia pertusa, the major structure-forming coral in the deep sea, is the dominant scleractinian off the southeastern U.S. This species has a cosmopolitan distribution, occurring on the southeastern U.S. slope, in the Gulf of Mexico, off Nova Scotia, in the northeastern Atlantic, the South Atlantic, the Mediterranean, Indian Ocean and in parts of the Pacific Ocean over a depth range of 50 to 2170 m (Cairns 1979; Rogers 1999). The 3380 m depth record off New York for *L. pertusa* reported by Squires (1959) was based on a misidentifed specimen (Cairns 1979). Coral habitats dominated by *L. pertusa* are common throughout the southeastern U.S. from about 370 to at least 800 m depth.

Although *Lophelia* may occur in small scattered colonies attached to various hard substrata, it also forms complex, high profile features. For instance, off North Carolina, *Lophelia* forms what may be considered classic mounds that appear to be a sediment/coral rubble matrix topped with almost monotypic stands of *L. pertusa* (Figure 6.3). Along the sides and around the bases of these banks are rubble zones of dead, gray coral pieces which may extend large distances away from the mounds. To the south sediment/coral mounds vary in size, and *L. pertusa* and other hard and soft corals populate the abundant hard substrata of the Blake Plateau in great numbers (Figures 6.4 and 6.5).

Data are lacking on how *Lophelia* coral banks in the southeastern U.S. are formed. Hypotheses for coral mound formation in the northeastern Atlantic were proposed (Hovland et al. 1998; Hovland and Risk 2003; Masson et al. 2003), but it is unclear how relevant these are off the southeastern U.S. The mounds off North Carolina and those in other locations off the southeastern U.S. (particularly east of south-central Florida) appear to be formed by successive coral growth, collapse, and sediment entrapment (Wilson 1979; Ayers and Pilkey 1981; Paull et al. 2000; Popenoe and Manheim 2001). Other coral formations in the area (especially on the Blake Plateau) seem to form by coral colonization of appropriate hard substrates, without mound formation by the corals. If bottom currents are too strong, mound formation may be prevented (Popenoe and Manheim 2001) because sediments cannot be trapped. Ayers and Pilkey (1981) suggested that Gulf Stream currents may erode coral mounds, and that present coral bank sizes may be related to historical displacements of that current. Assuming currents also carry appropriate foods, it may be that currents with variable speeds or at least currents of moderate speeds (fast enough to facilitate filter feeding but not too fast to prevent sediment entrapment) coupled with a supply of sediment are the conditions necessary to facilitate coral mound formation (Rogers 1999). Regardless of how coral formations are created, we agree with Masson et al. (2003) that elevated topography appears to be an important attribute for well developed coral communities.

Deep-coral reefs are fragile and susceptible to physical destruction (Fossa et al. 2002). It is estimated that these deep reefs may be hundreds to thousands of years old (Neumann et al. 1977; Wilson 1979; Ayers and Pilkey 1981; Mikkelsen et al. 1982; Mortensen and Rapp 1998); however, aging data are so limited (especially in the western Atlantic) that age of coral mounds in the western Atlantic is unclear. Recent drilling on coral mounds off Ireland indicated that these structures started forming over two million years ago and that formation was not related to hydrocarbon seeps (Williams T et al. 2006). While the genetic structure (gene flow, population relationships, taxonomic relationships) of *Lophelia* in the northeastern Atlantic is being described (Le Goff-Vitry et al. 2004), such studies are just beginning in the western Atlantic (C. Morrison et al. unpublished data). Preliminary genetic results from the southeast region suggest that the population structure of *L. pertusa* is more diverse than expected (C. Morrison et al. unpublished data). Understanding the population genetics and gene flow will provide insights into coral biology, dispersal and distribution of deep corals off the southeastern U.S.

Although *Lophelia* is the dominant hard coral off North Carolina, other scleractinians contribute to the overall complexity of the habitat (Table 6.1). Overall, species diversity of scleractinians increases south of Cape Fear, NC, but *L. pertusa*

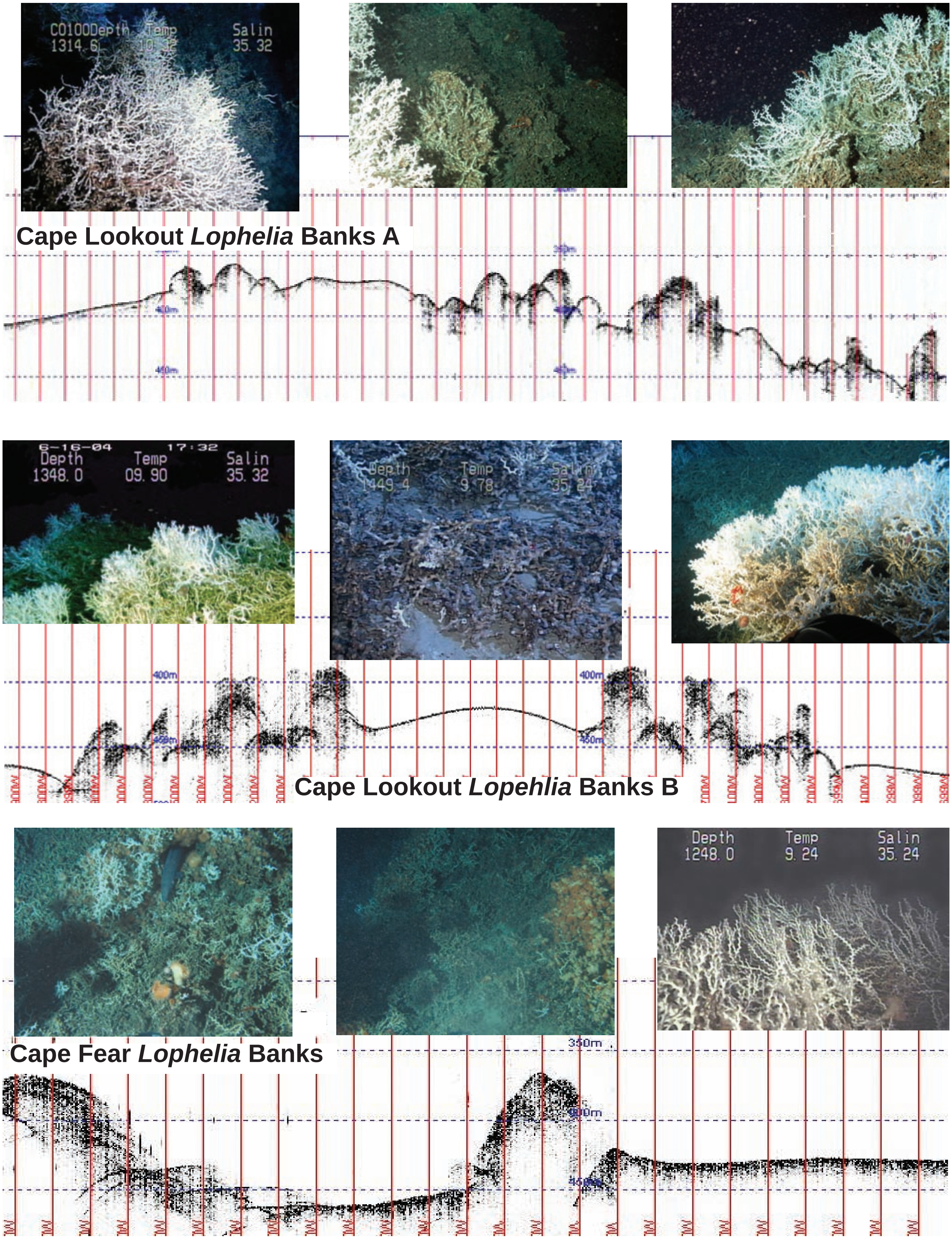


Figure 6.3. Depth sounder profiles and selected bottom views of the three North Carolina *Lophelia* coral banks. Top panel shows living (white) and dead (gray) corals near and on ridge tops. Middle panel also illustrates various live and dead corals as well as coral rubble (center photo). Bottom panel shows mixed corals, anemones, and conger eel (left photo), slope covered with anemones and corals (center photo), and the slender upright growth form of *Lophelia* (right photo). Habitat photographs do not correspond to a particular location on the depth sounder profiles. Profiles and photo credit: Ross et al. unpublished data.

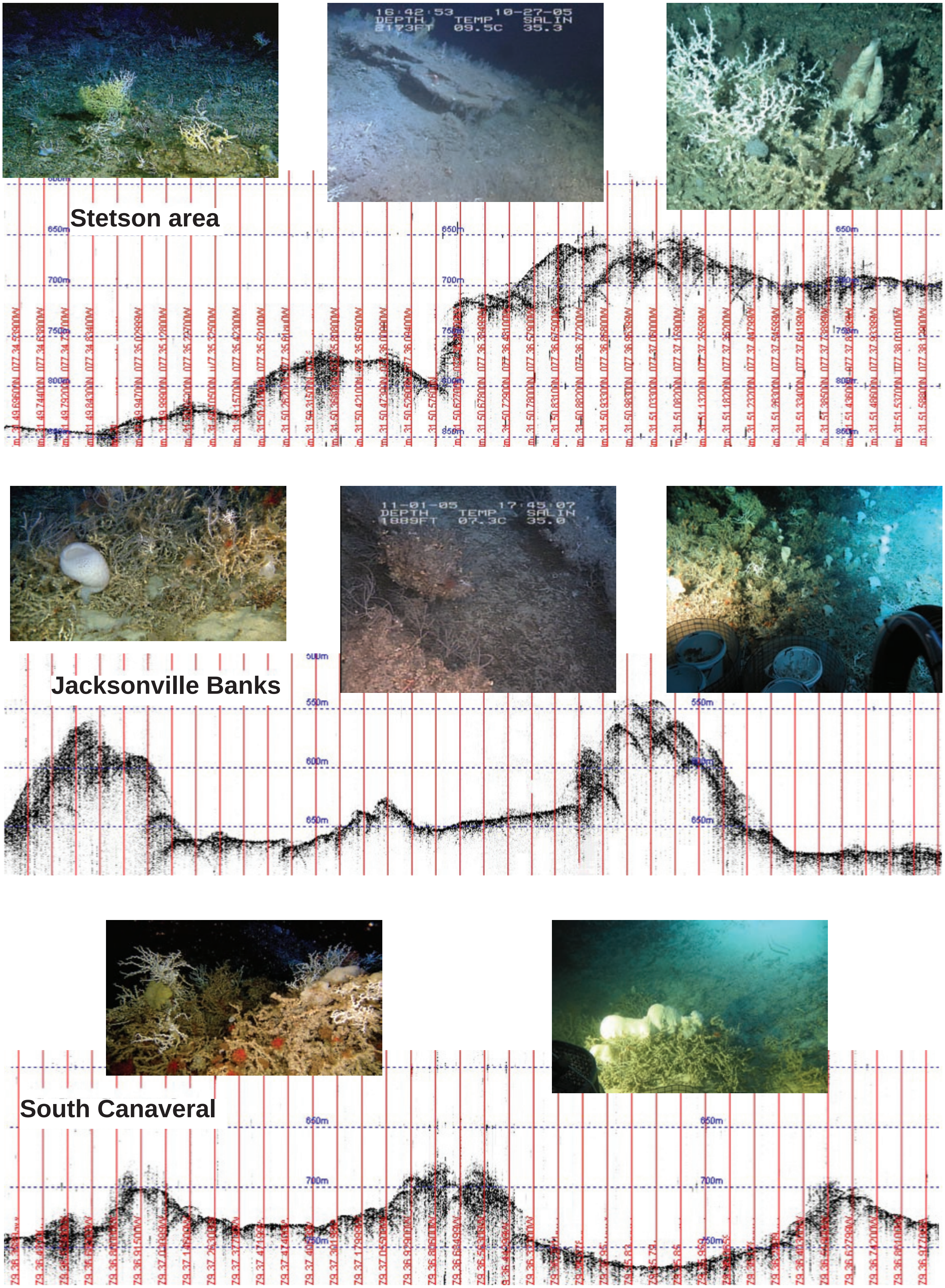


Figure 6.4. Depth sounder profiles and selected bottom views of coral (and sponge) habitats on the Blake Plateau south of North Carolina. Habitat photographs do not correspond to a particular location on the depth sounder profiles. Profiles and photo credit: Ross et al. unpublished data.

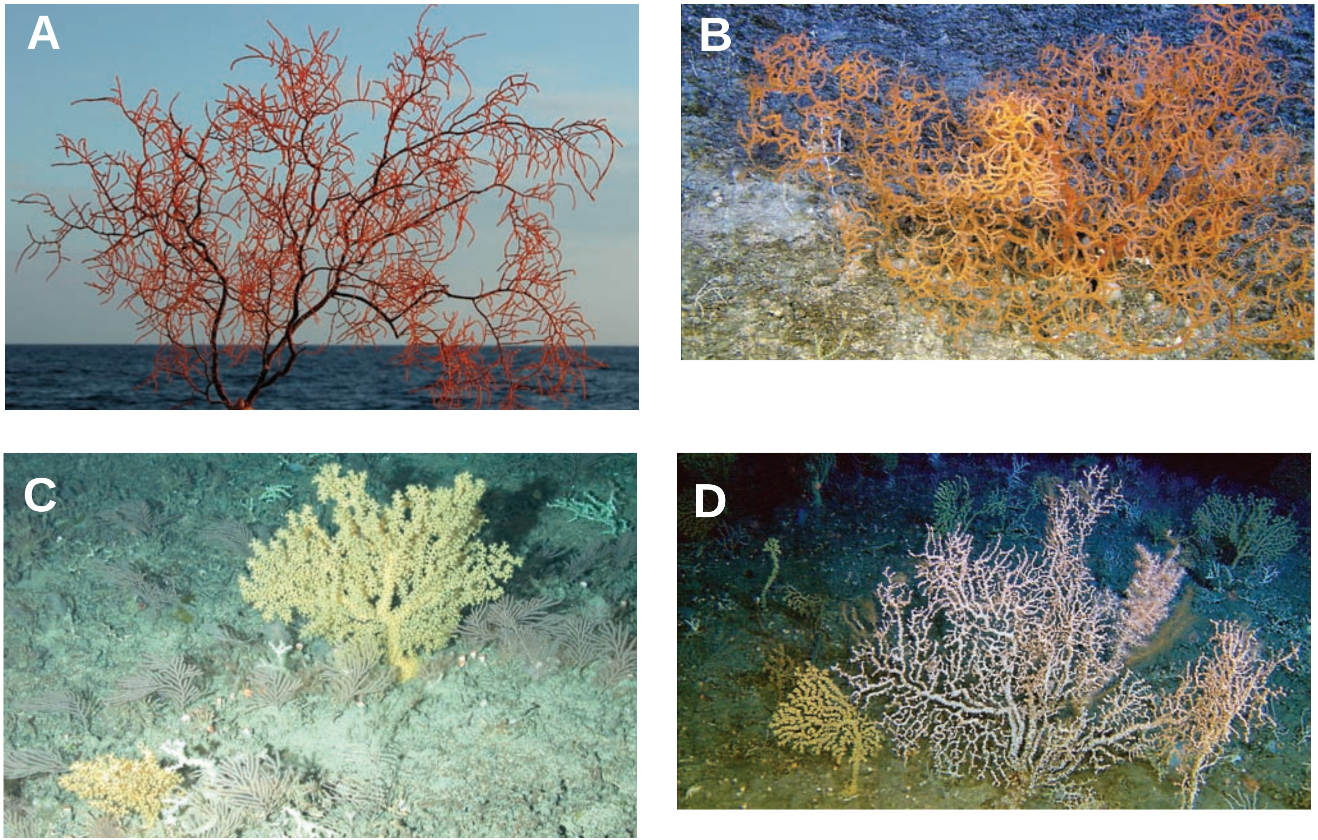


Figure 6.5. Examples of black (A,B; *Leiopathes* spp., possibly *Leiopathes glaberrima*), bamboo (D; *Keratoisis* spp., possibly *K. ornata*) and gold (E; *Gerardia* sp.) corals commonly found on the Blake Plateau south of North Carolina. Other corals (C) have not yet been identified. Photo credit: Ross et al. unpublished data.

is still dominant. For example, the colonial corals *Madrepora oculata* and *Enallopsammia profunda*, rare off Cape Lookout, NC, are relatively common south of Cape Fear, NC. These hard corals tend not to occur singly or as species-specific mounds, but rather live on or adjacent to the *Lophelia* mounds. A variety of solitary corals (Appendix 6.1) are also found off the southeastern U.S. Individuals are often attached to coral rubble or underlying hard substrata. Most species appear to be either uncommon or rare. But, in some instances, particularly in the central portion of the region, local abundance can be high. For example, aggregations of *Thecopsammia socialis* and *Bathypsammia fallosocialis* carpet the bottom adjacent to reef habitat at study sites off South Carolina and northern Florida (Ross et al., unpublished data).

b. *Black corals* (Class Anthozoa, Order Antipatharia)

Black corals (Families Leiopathidae and Schizopathidae, ca. four species) are important structure-forming corals on the southeastern U.S. slope (Figure 6.5; Table 6.1). These corals occur locally in moderate abundances, but their distributions seem to be limited to the region south of Cape Fear, NC. Colonies may reach heights of 1-2 m. Black coral colonies, occurring singly or in small aggregations, may be observed either in association with hard coral colonies or as separate entities. Some of these living components of the deep reefs attain ages of hundreds to thousands of years (Williams B et al. 2006; Williams et al. in press; C. Holmes and S.W. Ross, unpublished data), and thus, along with gold corals, are among the oldest known animals on Earth. Black corals form annual or regular bands, and these bands contain important chemical records on past climates, ocean physics, ocean productivity, pollution, and data relevant to global geochemical cycles. An effort to investigate these geochemical data is underway by U.S. Geological Survey (C. Holmes and S.W. Ross).

c. *Gold corals* (Class Anthozoa, Order Zoanthidae)

Gerardia spp. colonies are found most often singly away from other coral structure, but these corals are also found associated with colonies of other structure-forming corals such as *Lophelia pertusa*, *Keratoisis* spp., or antipatharians (*Leiopathes* spp.). Very little is known about this group of organisms. They apparently exhibit slow growth, reaching ages of at least 1800 years old (Griffin and Druffel 1989; Druffel et al. 1995) and may be valuable in paleoecology studies.

Table 6.1. Attributes of structure forming deep-sea corals of the southeastern United States.

Taxa	Reef-Building	Abundance	Max Colony Size	Morphology	Associations with Other Structure-Forming Invertebrates	Colony Spatial Dispersion	Overall Structural Importance
Lophelia pertusa	Yes	High	Large	Branching	Many	Clumped	High
Solenosmilia variabilis	No	Low	Small	Branching	Many	Clumped	Low
Enallopsammia profunda	No	Low-Medium	Small-Medium	Branching	Many	Clumped	Low-Medium
Madrepora oculata	No	Low	Small	Branching	Many	Clumped	Low
Oculina varicosa	Yes	High	Large	Branching	Many	Clumped	High
Madracis myriaster	No	Low	Small-Medium	Branching	Many	Clumped	Low
Leiopathes glaberrima	No	Medium	Medium-Large	Branching	Many	Solitary	Medium
Bathypathes alternata	No	Low	Medium-Large	Branching	Many	Solitary	Low
Keratoisis spp.	No	Medium	Medium-Large	Branching	Many	Solitary	Medium

Table Key

Attribute	Measure
Reef-Building	Yes/No
Relative Abundance	Low/ Medium/ High
Size (width or height)	Small (< 30cm)/ Medium (30cm-1m)/ Large (>1m)
Morphology	Branching/ Non-branching
Associations	None/ Few (1-2)/ Many (>2)
Spatial Dispersion	Solitary/ Clumped
Overall Rating	Low/ Medium/ High

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

The gorgonians are by far the most diverse taxon on the southeastern U.S. slope represented by seven families, 17 genera, and 32 species (Appendix 6.1). The diversity of gorgonians increases dramatically south of Cape Fear, NC. Additional sampling is likely to increase the numbers of known species in this group for this region. To date, material we collected off Jacksonville, FL represented a newly described species (*Thourella bipinnata* Cairns 2006); the specimen of *Chrysogorgia squamata* also collected off Jacksonville represented the fifth known specimen of this species and increased our knowledge of its geographic range (previously known only from the Caribbean).

Bamboo corals (Family Isididae, four species), possibly the best known members of this group because of their larger size and distinctive morphology, are also important structure-forming corals off the southeast region. (Figure 6.5; Table 6.1). They occur locally in moderate abundances, and their distributions also seem to be limited to the region south of Cape Fear, NC. Colonies may reach heights of 1-2 m. Bamboo coral colonies occur either singly or in small aggregations and may be observed either in association with hard coral colonies or as separate entities.

e. *True soft corals* (Class Anthozoa, Order Alcyonacea)

Three families, Alcyoniidae, Nephtheidae, and Nidaliidae, comprise the Alcyonacea off the southeastern U.S. No family is speciose; total known diversity for this group is only six species (Appendix 6.1). The most abundant species observed in the region is *Anthomastus agassizi*, which is relatively abundant at sites off Florida. It is usually attached to dead *Lophelia*, but some individuals have also been observed on dermosponges and coral rubble. The majority of the alcyonacean species are smaller in size, both in vertical extent and diameter, than the gorgonians. Thus, these corals add to the overall structural complexity of the habitat by attaching to hard substrata such as dead scleractinian skeletons and coral rubble.

Stoloniferans, a suborder (Stolonifera) within the Alcyonacea, are represented by one family (Clavulariidae) off the southeast region. Six species from four genera have been reported from the region (Appendix 6.1). One species, *Clavularia modesta*, is widespread throughout the western Atlantic; the other five species are known from North Carolina southward to the Caribbean.

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

Little is known about pennatulids (sea pens) off the southeastern U.S. It is unlikely that this group contributes significantly to the overall complexity and diversity of the system. No sea pens have been observed during recent surveys (Ross et al., unpublished data) and based on museum records, only one species (*Kophobelemnon sertum*) is known in the region (Appendix 6.1).

g. *Stylasterids* (Class Hydrozoa, Order Anthoathecatae)

Although not found in great abundances, stylasterids (lace corals) commonly occur off the southeastern U.S. Seven species representing four genera have been reported from the region (Appendix 6.1). Individuals observed *in situ* are often attached to dead scleractinian corals or coral rubble. Abundance and diversity of stylasterids increase southward from the Carolinas.

V. SPECIES ASSOCIATIONS WITH DEEP CORAL COMMUNITIES

Oculina Banks (<150 m)

The fish community on the Florida shelf edge *Oculina* banks is typical of the southeastern U.S. shelf edge reef fauna (see review in Quattrini and Ross 2006). At least 73 species of fishes are known from the *Oculina* reefs (GOMFMC and SAFMC 1982; Koenig et al. 2005; Reed et al. 2006), and like the invertebrate community, this is a sub-tropically derived fauna. In recent years commercial fishing on these reefs has significantly depleted members of the snapper-grouper complex and caused habitat destruction (Koenig et al. 2000, 2005). Some groupers, *Mycteroperca microlepis* (gag) and *M. phenax* (scamp), use the reefs as spawning aggregation sites (Gilmore and Jones 1992); however, these have also been negatively impacted by habitat destruction (Koenig et al. 2000).

The Florida *Oculina* reefs support a diverse invertebrate fauna with mostly sub-tropical affinities (Figure 6.2). Densities of associated invertebrates rival those of shallow coral reef systems (see review in Reed 2002b). Avent et al. (1977) presented a preliminary list of benthic invertebrates dredged from some *Oculina* mounds. Analysis of 42 small *Oculina* colonies yielded about 350 invertebrate species, including 262 mollusc species (Reed and Mikkelson 1987), 50 decapod crustacean species (Reed et al. 1982), 47 amphipod species, 21 echinoderm species, 15 pycnogoid species, and 23 families of polychaetes (Reed 2002b). The invertebrate community has been reduced by habitat destruction (Koenig et al. 2000). Although *Oculina* habitats appear to have more associated mobile macroinvertebrates than deeper coral areas, large sponges and soft/horny corals are less abundant (Reed et al. 2006).

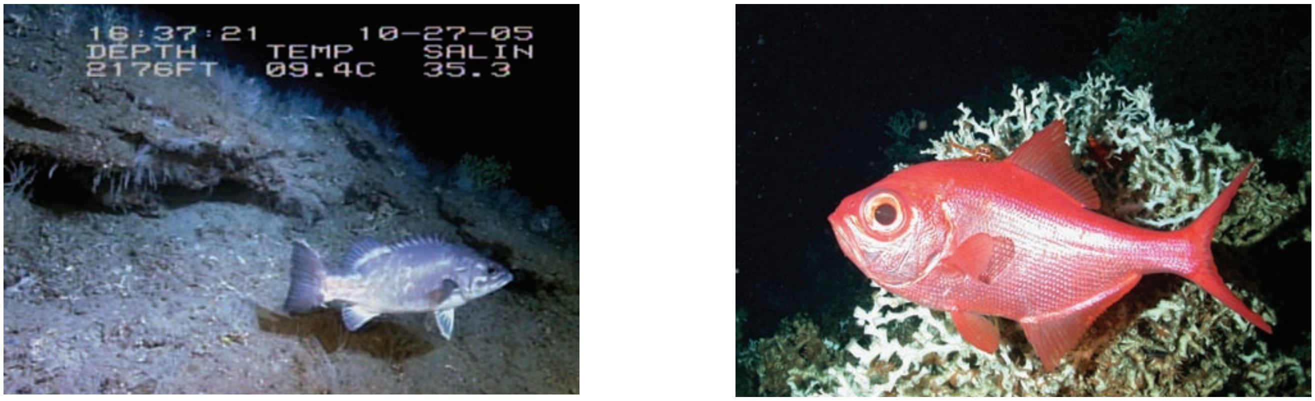
Deep-sea slope coral areas (>150 m, but most >300 m)

Deep coral habitat may be more important to western Atlantic slope species than previously known. Some commercially valuable deep-water species congregate around deep-coral habitat (Table 6.2). Various crabs, especially galatheoids, are abundant on the deep reefs, playing a role of both predator on and food for the fishes. Other invertebrates, particularly ophiuroids, populate the coral matrix in high numbers. On the relatively barren Blake Plateau, reefs (coral and hardgrounds) and surrounding coral rubble habitat seem to offer abundant shelter and food.

Table 6.2. Dominant benthic fish species (in phylogenetic order) observed and/or collected during submersible dives (2000-2005) on or near southeastern U.S. *Lophelia* habitat based on Ross and Quattrini (2007). Asterisk (*) indicate commercially important species

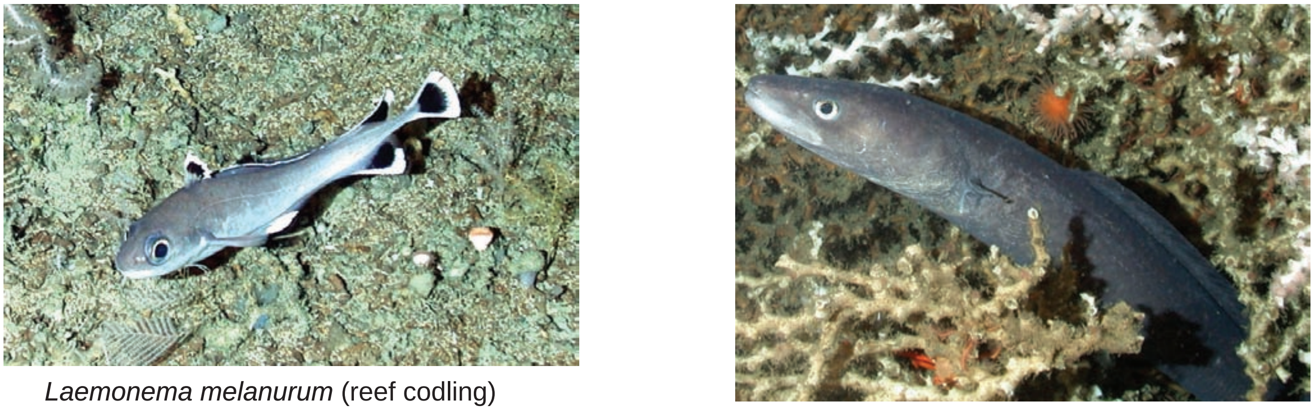
Scientific name	Common name (if known)
Myxinidae (mixed Myxine glutinosa and Eptatretus spp.)	hagfishes
Scyliorhinus retifer	chain dogfish
Scyliorhinus meadi	
Cirrhigaleus asper	roughskin dogfish
Dysommina rugosa	
Synaphobranchus spp.	cutthroat eels
*Conger oceanicus**	conger eel
Netenchelys exoria	
Nezumia sclerorhynchus	
Laemonema barbatulum	shortbeard codling
Laemonema melanurum	reef codling
Physiculus karrerae	
Lophiodes beroe	
Hoplostethus occidentalis	western roughy
*Beryx decadactylus**	red bream
*Helicolenus dactylopterus**	blackbelly rosefish
Idiastion kyphos	
Trachyscorpia cristulata	Atlantic thornyhead
*Polyprion americanus**	wreckfish

There are few deep-coral ecosystem references for the southeast region related to fishes, and those are generally qualitative (fishes neither collected nor counted) or fishes were not a specific target of the research (Popenoe and Manheim 2001; Weaver and Sedberry 2001; Reed et al. 2005, 2006). In the most detailed study of fishes to date, Ross and Quattrini (2007) identified 99 benthic or benthopelagic fish species on and around southeastern U.S. deep-coral banks, 19% of which yielded new distributional data for the region. Additional publications resulting from their fish database documented the anglerfish fauna (Caruso et al. 2007), midwater fish interactions with the reefs (Gartner et al. in review), a new species of eel (McCosker and Ross in press), and a new species of hagfish (Fernholm and Quattrini in press). Although some variability in fish fauna was observed over this region, most of the deep-coral habitat was dominated by relatively few fish species (Table 6.2, Figure 6.6). Many of these species are cryptic, being well hidden within the corals (e.g., *Hoplostethus occidentalis*, *Netenchelys exoria*, *Conger oceanicus*). Various reef habitats were characterized by *Laemonema melanurum, L. barbatulum, Nezumia sclerorhynchus, Beryx decadactylus*, and *Helicolenus dactylopterus* (Ross and Quattrini 2007). Nearby off reef areas were dominated by *Fenestraja plutonia*, *Laemonema barbatulum, Myxine glutinosa*, and *Chlorophthalmus agassizi*. *Beryx decadactylus* usually occurs in large aggregations moving over the reef, while most other major species occur as single individuals. The morid, *Laemonema melanurum*, is one of the larger fishes abundant at most sites with corals. This fish seems to rarely leave the prime reef area, while its congener *L. barbatulum* roams over a broader range of habitats. Although *Helicolenus dactylopterus* (Figure 6.6) can



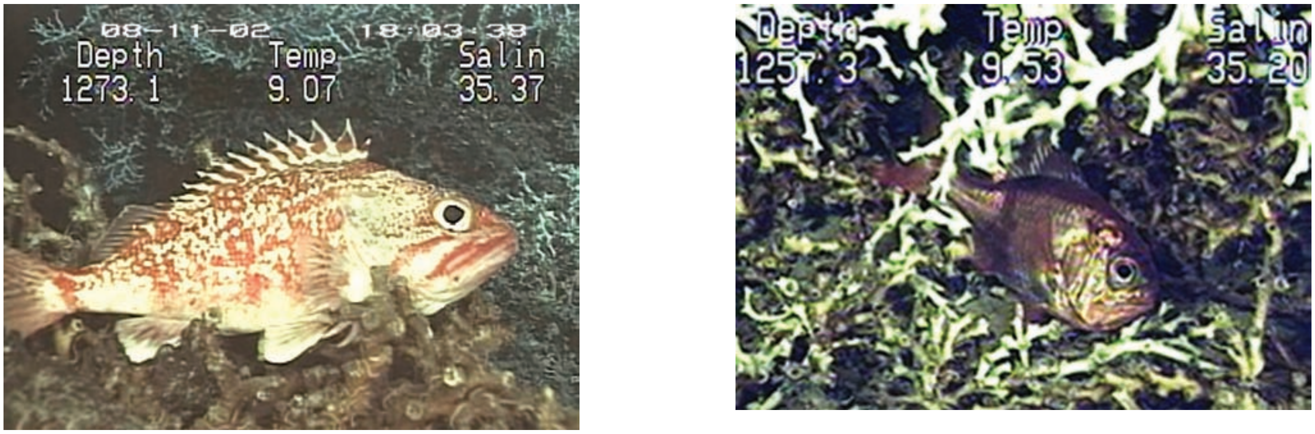
Polyprion americanus (wreckfish)

Beryx decadactylus (red bream)



Laemonema melanurum (reef codling)

Conger oceanicus (conger eel)



Helicolenus dactylopterus (blackbelly rosefish)

Hoplostethus occidentalis (western roughy)

Figure 6.6 Photographs of some common fish species of the southeastern US deep (> 200 m) coral habitats Photographs credit: S.W. Ross.

be common in all habitats, it occurs most often around structures. It is intimately associated with the coral substrate, and it is abundant around deep-reef habitat. Results (Ross and Quattrini 2007) suggested that some of the fishes observed around the deep-coral habitats may be primary (obligate) reef fishes.

One of the most impressive biological aspects of these coral habitats (aside from the corals themselves) is the diverse and abundant invertebrate fauna (Table 6.3 and Reed et al. 2006). *Eumunida picta* (galatheoid crab; squat lobster) and *Novodinia antillensis* (brisingid seastar) were particularly obvious (Figure 6.7), perched high on coral bushes to catch passing animals or filter food from the currents. One very different aspect of the North Carolina deep-coral habitat compared to the rest of the southeast region is the massive numbers of the brittle star, *Ophiacantha bidentata*, covering dead coral colonies, coral rubble, and to a lesser extent, living *Lophelia* colonies (Figure 6.7). It is perhaps the most abundant macroinvertebrate on these banks and may constitute a major food source for fishes (Brooks et al. 2007). In places the bottom is covered with huge numbers of several species of anemones (Figure 6.7). The hydroid fauna is also rich with many species being newly reported to the area and some species being new to science (Henry et al. in press). The abundance of filter feeders suggests a food rich habitat. Various species of sponges, echinoderms, cnidarians (Messing et al. 1990) and crustaceans (Wenner and Barans 2001) also have been reported from deep-coral reefs off Florida, the northeastern Straits of Florida and the Charleston Bump region (Reed et al. 2006). Reed et al. (2006) provided a preliminary list of invertebrates, mostly sponges and corals, from some deep-coral habitats on the Blake Plateau and Straits of Florida; however, most taxa were not identified to species. Lack of data on the invertebrate fauna associated with deep corals is a major deficiency.

Although the invertebrate assemblage associated with northeastern Atlantic *Lophelia* reefs has been described as being as diverse as shallow water tropical coral reefs (e.g., Jensen and Frederickson 1992), data analysis of invertebrates associated with western Atlantic deep corals is too preliminary to speculate on the degree of species richness. Preliminary data on the invertebrate fauna (Nizinski et al. unpublished data) seem to indicate a faunal and habitat transition with latitude. In addition to changes in reef structure and morphology (see above), relative abundance within a single species decreases, overall species diversity increases, and numerical dominance between species decreases with decreasing latitude. In contrast to some fishes, the reef associated invertebrate assemblage appears to use deep reefs more opportunistically.

VI. STRESSORS ON DEEP CORAL ECOSYSTEMS OF THE SOUTHEASTERN U.S.

Very little direct information exists to evaluate the health or condition of deep-coral reefs along the coast of the southeastern U.S. However, the potential for impacts to deep-sea ecosystems is of great concern because communities at these greater depths are not able to sustain heavy fishing pressures, as the general longevity of their species, slow growth, and low dispersal rates often prevent recovery from damaging impacts (Koslow et al. 2000; Roberts 2002; Cheung et al. 2007). A large portion of the *Oculina* banks was closed to fishing due to destruction of habitat and concern for conservation of corals and the associated fauna. There is concern that fisheries may soon target other deep-coral ecosystems in the region.

Fishing Effects

Major human induced damage to habitat and biota has been documented on the east-central Florida shelf edge, *Oculina* reef tract. Extensive damage to corals and fish stocks from fishing operations was reported (Coleman et al. 1999; Koenig et al. 2000, 2005), including decreased numbers and biomass of corals, decreased amounts of coral habitat, and declining fish stocks. The primary fish targets (snapper, grouper, porgy) on the *Oculina* reefs are also generally considered overfished throughout the waters off the southeastern U.S. (SAFMC unpublished data).

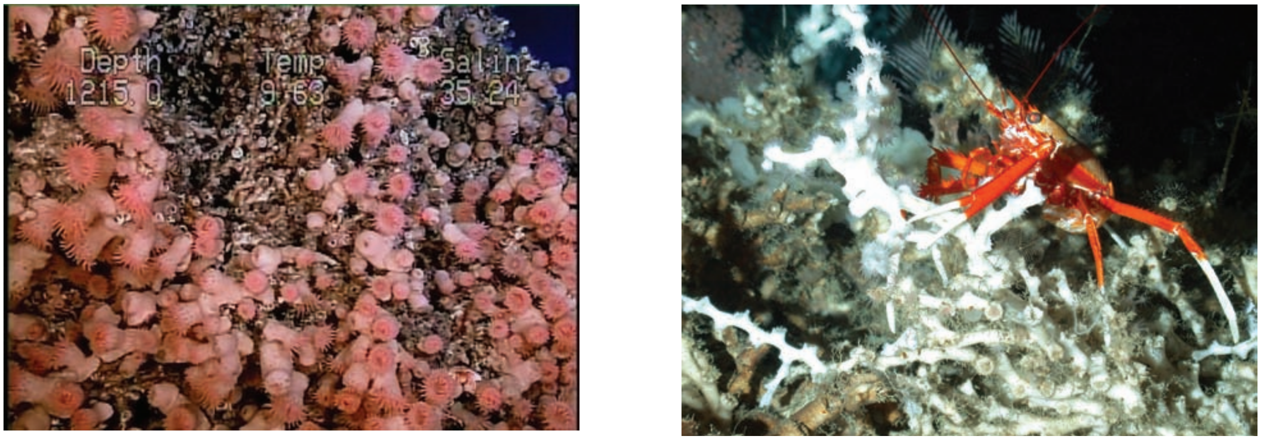
On the slope some commercially-exploited deep-water fishes, like *Polyprion americanus* (wreckfish; Vaughan et al. 2001) and *Helicolenus dactylopterus* (blackbelly rosefish), utilize *Lophelia* habitat extensively (Ross and Quattrini 2007). Swordfish have been observed along the deep reefs (Reed et al. 2006; Ross and Quattrini 2007). Other potentially exploitable species, such as royal red shrimps, rock crabs, golden crab, squid, bericiform fish species, and eels, are also associated with deep-coral habitats. Signs of past fishing effort (trash, lost gear) were observed on some banks, but the extent to which fishermen sample these areas is unknown; therefore, estimations of fishing impact (Table 6.4) are problematic. The potential for new deep-water fisheries on and around these banks is unknown. At this time our impression is that benthic fishing impacts to corals and benthic fishery species beyond 200 m in this region are minimal.

Table 6.3. Preliminary list of dominant benthic megainvertebrates observed or collected on or near southeastern U.S. deep coral habitats. Corals are listed separately in Appendix 6.1. References are 1= Nizinski et al. unpublished data, 2= Reed et al. 2006, 3 = Henry et al. in review.

Dominant Non-Coralline Invertebrate Taxa	
Phylum Porifera (Sponges) Class Demospongiae multiple species[1,2] Class Hexactinellida (glass sponges) multiple species[1,2] including *Aphrocallistes beatrix*[1]	Phylum Cnidaria Class Hydrozoa (Hydroids) multiple species (≥ 37 species)[3] Class Anthozoa Order Actinaria (anemones) multiple species including *Actinaugi rugosa* (Venus flytrap anemone)[1] Order Zoanthidea (zoanthids) multiple species[1,2]
Phylum Mollusca Class Cephalopoda Squids, *Ilex* sp.[1] Octopus, multiple species[1] Class Gastropoda *Coralliophila* (?) sp.[1]	Phylum Annelida Class Polychaeta (polychaetes) multiple species including *Eunice* sp.[1]
Phylum Arthopoda Subphylum Crustacea Class Malacostraca Order Decapoda Infraorder Anomura Family Chirostylidae (squat lobster) *Eumunida picta* [1,2] *Gastroptychus salvadori*[1] *Uroptychus* spp.[1] Family Galatheidae (squat lobster) *Munida* spp.[1] *Munidopsis* spp.[1] Superfamily Paguroidea (hermit crabs and their relatives) multiple species[1] Infraorder Brachyura Family Pisidae *Rochinia crassa* (inflated spiny crab)[1] Family Geryonidae *Chaceon fenneri* (golden deepsea crab)[1,2] Family Portunidae *Bathynectes longispina* (bathyal swimming crab)[1,2] Other taxa Shrimps, multiple species[1]	Phylum Echinodermata Class Crinoidea (crinoids) multiple species[1] Class Asteroidea (sea stars) multiple species[1,2] Order Brisingida (brisingid sea star) Family Brisingidae *Novodinia antillensis*[1] Class Ophiuroidea (brittle stars) multiple species[1], including *Ophiacantha bidentata*[1] Class Echinoidea (sea urchins) Order Echinoida Family Echinidae *Echinus gracilis*[1] *E. tylodes*[1] Order Echinothurioida Family Echinothuriidae *Hygrosoma* spp.[2] Order Cidaroida Family Cidaridae *Cidaris rugosa*[1] *Stylocidaris* spp.[2]

Effects Of Other Human Activities

Other anthropogenic activities could have negative impacts on deep-coral habitats, but presently most of these do not appear to be issues. Currently there is a federal moratorium on hydrocarbon exploration in this region, and there are no active offshore production operations. If this moratorium is lifted, the potential impacts to deep-coral habitat should be carefully considered. Cable laying could cause physical damage to coral habitat, but to date such damage has not been documented off the southeastern U.S. Construction of a proposed liquefied natural gas (LNG) terminal with associated benthic pipelines off south Florida could impact deep-coral habitat.

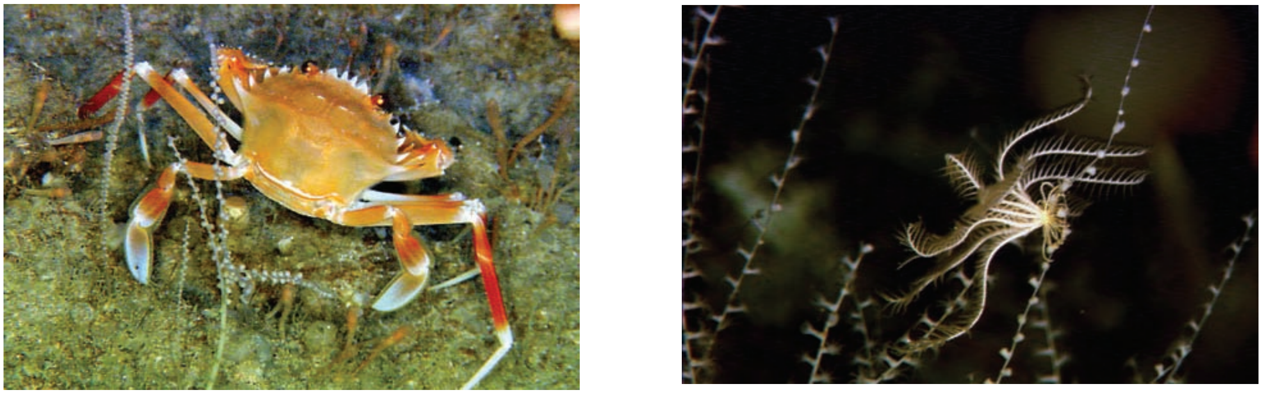


wall of unidentified anemones

Eumunida picta (squat lobster) on *Lophelia* coral

Novodinia antillensis (brisingid sea star)

Ophiacantha bidentata (brittle stars) intertwined within the *Lophelia* coral matrix and *Echinus* sp. top center.



Bathynectes longispinus (bathyal swimming crab)

Antedonidae (swimming crinoid)

Figure 6.7. Photographs of common invertebrates of the southeastern U.S. deep (>200 m) coral habitats. Photo credit: Ross et al. unpublished data.

Bottom disturbance through construction of offshore tanker ports may impact coral areas, especially off Florida where deep water is closer to shore. Construction of wind farms for energy production has been recently proposed for offshore areas. While these would likely be in waters shallower than those occupied by deep corals, designs for deeper water systems exist. Coral growth can keep up with a certain amount of sedimentation (Reed 2002b), but high rates of sedimentation are detrimental to corals (Rogers 1990). We are unaware of references

Table 6.4. Potential fishing gear impacts to deep water corals in the southeastern United States.

Gear Type	Severity of Impact	Extent of Impact	Geographic Extent of Use in Region	Overall Rating of Gear Impact
Bottom Trawl	High	High	Low	High
Mid-water Trawl	Low	Low	Low	Low
Dredge	High	Medium	Low	Medium
Bottom-set Longline	Medium	Low	Low	Low
Bottom-set gillnet	Medium	Low	Low	Low
Traps or Pots	Medium	Low	Low	Low

documenting sedimentation impacts to deep corals of the southeast region (except *Oculina*, Reed 2002b), and if they exist, most such impacts would usually not be anthropogenic. Active disposal activities (e.g., industrial, municipal, or military wastes) seem to be either rare or absent in deep waters of this region. There do not appear to be any deep coral harvesting activities off the southeastern U.S., although there is potential for this (GOMFMC and SAFMC 1982). Some mineral resources exist throughout the area (e.g., sand, manganese), but we are unaware of any current mining of these along the southeastern U.S. shelf edge or slope.

Climate change has not noticeably impacted southeastern U.S. deep corals. Impacts from rising ocean temperature to azooxanthellate deep corals would be different, but unknown, than those to shallow corals where zooxanthellae are expelled. Changes in sea level (increases) are likely to have little impact. However, climate changes that would impact the speed and direction of the Gulf Stream current or the overall North Atlantic conveyor system could have far reaching and difficult to predict impacts on deep corals. Changes in these currents could affect sediment transport, food delivery, dispersal mechanisms, as well as ambient temperature and salinity conditions. Ocean acidification from increased atmospheric CO_2 is a recently identified potential impact to corals (Guinotte et al. 2006).

To date only one invasive species, the lionfish (*Pterois volitans*), has been documented from this area within a depth range to impact the *Oculina* bank communities (Meister et al. 2005). While widespread and seemingly abundant, lionfish have not yet been reported from the *Oculina* area. Their maximum reported depth off the southeastern U.S. is 99 m (Meister et al. 2005); thus, they are not expected at the deeper slope coral areas.

VII. MANAGEMENT OF FISHERY RESOURCES AND HABITATS

All scleractinian and black corals off the southeastern U.S. are listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The purpose of this international agreement between governments is to ensure that international trade in specimens of wild animals and plants does not threaten their survival. Thus, CITES imposes restrictions on international trade in non-fossil corals.

The South Atlantic Fishery Management Council, in cooperation and collaboration with the National Marine Fisheries Service (NMFS), is responsible for management of habitat and most fishery resources in federal waters of the southeastern U.S. (see www.safmc.net). Management is executed through single species or species group fishery management plans. Plans that regulate the snapper/grouper complex, coastal pelagics, and dolphin/wahoo relate to species using the shelf edge *Oculina* banks. Fewer species are exploited in the deeper slope waters. Harvest of golden deep-sea crab (*Chaceon fenneri*) is regulated through a fishery management plan, and wreckfish are managed as part of the snapper/grouper complex. The SAFMC is moving from single species management toward an ecosystem-based approach which incorporates a broader appreciation of ecosystem interactions.

Swordfish, tunas, sharks and billfishes are managed by the Highly Migratory Division of NMFS.

Although not applicable to deep corals in this region, other species (e.g., sea turtles, whales) are protected through such regulations as the Endangered Species Act and the Marine Mammal Protection Act. Sea turtles may occur on the *Oculina* banks; however, most of the slope deep-coral habitat is too deep for sea turtles and many marine mammals. In areas to be explored for hydrocarbons or mined for minerals within the EEZ, the Minerals Management Service (U.S. Dept. of Interior) requires geohazards surveys, including documentation of corals, and conducts environmental impact reviews of these activities.

Protection of coral habitat, including deep-water forms, in this region was established in a Coral, Coral Reef, and Live/Hardbottom Habitat Fishery Management Plan (FMP) under the Magnuson-Stevens Fishery Conservation and Management Act (GOMFMC and SAFMC 1982). This FMP summarized biological and other data on all corals off the southeastern U.S. and in the Gulf of Mexico. Additionally, optimum harvest of stony corals and sea fans throughout the waters off the southeastern U.S. was set at zero (collection for education and research purposes is permitted). The recent reauthorization of the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (P.L. 109-479) allows councils to designate zones for the protection of deep corals and requires research on and monitoring of deep coral habitats. The only deep coral protected area off the southeastern U.S., the *Oculina* Habitat Area of Particular Concern (HAPC), was described in GOMFMC and SAFMC (1982), but no other deep-coral areas were so designated. Designation of the *Oculina* banks as an HAPC became final in 1984, and use of bottom disturbing gear was prohibited (Reed 2002b). Over the next 14 years, these regulations were refined and expanded in a series of Amendments to the FMP. Increased protection of the *Oculina* banks was granted in 1994, with a total fishing ban within the original HAPC. The HAPC was doubled in size in 2000, and the new expanded area is now closed to towed bottom gear. In 2004, the ban on fishing was extended indefinitely.

No other deep-coral habitats are designated or fall within marine protected areas (MPAs), HAPCs or marine sanctuaries. No corals in the area are listed as Endangered or Threatened under the Endangered Species Act. If other deep-coral reefs prove to be important habitat with a unique fauna (as they seem to be), these reefs should be considered for protection as are the *Oculina* coral reefs. There are a variety of potential threats to the deep-coral habitats (see above). MPAs or HAPCs may be viable options for protecting these systems. However, considerable amounts and types of data, especially detailed maps, are critical for evaluating how and whether to protect deep-coral ecosystems (Miller 2001).

The SAFMC is currently evaluating management strategies for southeastern U.S. deep corals. Considering the needs of the SAFMC to evaluate and manage deep-water habitats in a timely manner, the brief, unpublished descriptions of southeastern U.S. deep-coral banks provided by Ross (2006) and Reed (2004) served as interim tools facilitating potential management options for deep-coral habitats. Based on these reports six large areas were recommended as deep coral HAPCs; these recommendations were modified in 2006 (Figure 6.8). These proposed HAPC areas are included in the current regional FMP and Ecosystem Plan (R. Pugliese, pers. comm.). A research plan is being prepared by a SAFMC committee to outline gaps in our knowledge and to address the immediate need for data pertaining to deep-coral habitats on the southeastern U.S. continental slope.

VIII. REGIONAL PRIORITIES TO UNDERSTAND AND CONSERVE DEEP CORAL COMMUNITIES

Basic data are lacking for the majority of coral habitats >200 m. Recommendations below largely result from basic data needs. Considering their habitat value for deep-sea communities, their fragility, and a general lack of data, locating, describing, and mapping deep corals and conducting basic biological studies in these habitats are global and regional priorities (McDonough and Puglise 2003; Roberts and Hirshfield 2003; Puglise et al. 2005).

Recommendations

- Detailed mapping of the southeastern U.S. shelf edge and slope is critical to better understand these habitats and evaluate their contributions to slope ecology. Such mapping is the foundation for most other research and management activities. Multibeam mapping should be conducted as soon as possible, especially in the depth range of 350-800 m. While this recommendation relates to the whole slope off the southeastern U.S., priority should be given to known coral sites and areas of suspected coral mounds.

- Of the many important ecological/biological studies that could be proposed, a broad trophodynamics study of coral banks and surrounding areas (whole water column) would provide the most impact for funds expended. Knowing the flow of energy in a system facilitates evaluation of anthropogenic impacts and allows predictions about the consequences of natural change. Such information is critical to ecosystem based management.

- Species composition and distributions of deep corals within the region require better documentation. Collection efforts for corals for identification by taxonomic experts, should be initiated. The overall deep-coral fauna is also poorly known. Better documentation of the whole living habitat matrix and associated fauna, as was done for *Oculina* reefs, is needed.

- Deep corals and the underlying mounds need to be aged. Accurate growth data on the major structure forming corals (e.g., *Lophelia*, *Madrepora*, bamboo and black corals) are

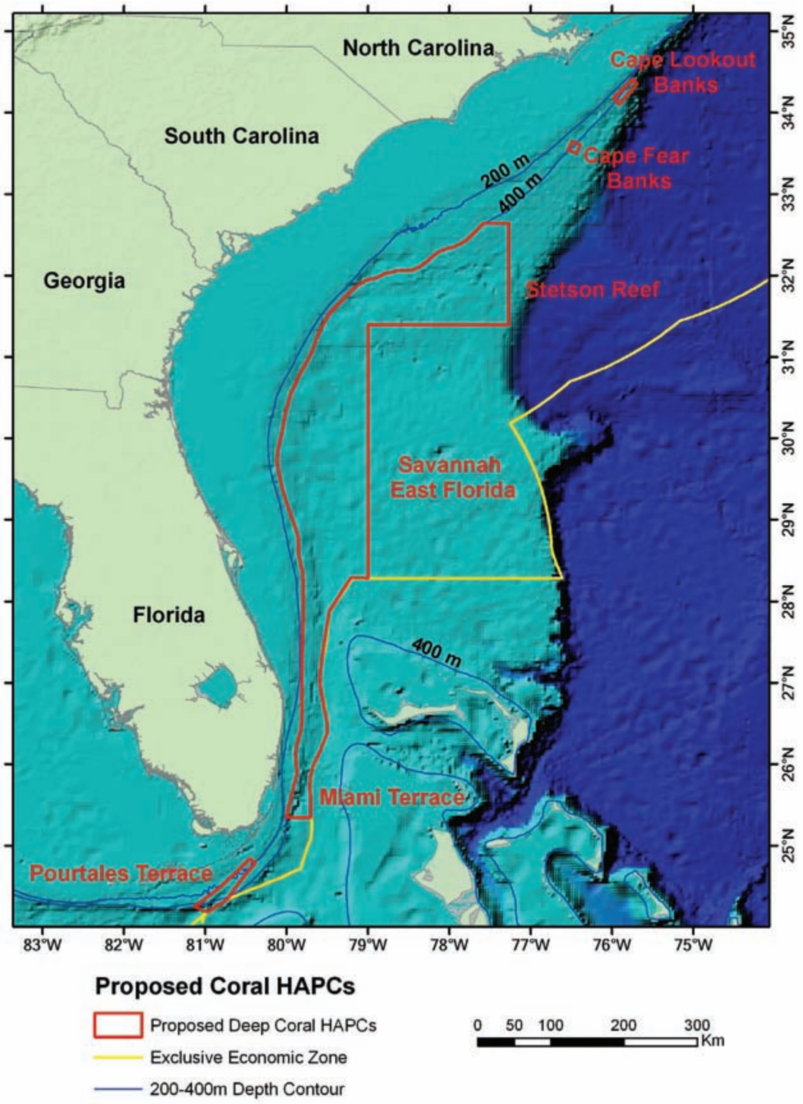


Figure 6.8. Deep coral areas (red outlines) proposed for protection as Habitat Areas of Particular Concern by the South Atlantic Fishery Management Council.

critical to evaluate how banks are formed and their present status (accreting, eroding). This type of research may need to be coupled with local sedimentation and bottom current studies.

- Significant amounts of paleoclimate or paleoenvironmental data can be obtained from some coral species. Such studies should be pursued.

- Genetic studies should continue or be initiated for the major coral species and dominant associated fauna to examine taxonomic status, dispersal, relationships among coral banks, and community genetics.

- If protected areas are established for southeastern U.S. deep-coral banks, plans for long term monitoring, research, education, and enforcement should accompany this strategy. The SAFMC is developing such a plan. Funding should be made available to execute the plans.

- Any deep-water fisheries that currently exist or that develop on or near the deep-coral banks should be carefully monitored and regulated as deep-water fauna are highly vulnerable to over fishing, and the habitat is subject to permanent destruction.

IX. CONCLUSION

The southeast region contains a huge area of diverse deep-coral habitat. Rugged topography and hard substrata are common on the outer shelf edge and slope and this physical structure facilitates development of coral mounds and other coral habitats. However, detailed maps are lacking, and a major mapping effort must be initiated. Accurate maps are crucial to our understanding of the extent of this habitat, for planning research, and to our ability to manage deep-coral habitat. A recent multibeam mapping cruise (Ross and Nizinski unpublished data), covering most of the known North Carolina sites and portions of the Stetson banks, revealed numerous mounds (probably coral mounds), ridges, scarps, and depressions that were unknown. Based on these and other findings, it seems probable that the waters off the southeastern U.S. contains the greatest diversity and concentrations of reef building deep corals on the U.S. continental slope.

The three North Carolina *Lophelia* areas represent the northernmost deep-coral banks off the southeastern U.S. Significant deep-coral habitats are not apparent on the U.S. East coast again until north of Cape Cod. Because these banks seem to be a northern terminus for a significant zoogeographic region, they may be unique in biotic resources as well as habitat expression. The banks so far examined off North Carolina are different from much of the coral habitat to the south on the Blake Plateau. The North Carolina features are dominated by dense thickets of living *L. pertusa* that cover the tops and sides of the banks; the banks are surrounded by extensive coral rubble zones. Unlike areas to the south, the diversity of other corals is low.

Southeastern U.S. deep-coral systems support a well developed community that appears to be faunistically different from surrounding non-reef habitats. The fish community on these deep reefs is composed of many species that do not (or at least rarely) occur off the reefs (Ross and Quattrini 2007). Therefore, they may be considered primary reef fishes, in a way similar to those on shallow reefs. Many fish species thought to be rare and/or outside their reported ranges have been found on these reefs (Ross and Quattrini 2007). Most likely these species only appeared to be rare because they occurred in areas that were difficult to sample by conventional means. Thus, these deep-coral habitats support a fish community that appears to be tightly coupled to the habitat and has essentially escaped detection until recently. Invertebrate communities are also very diverse and well developed; however, their associations with the reef habitat seem to be more opportunistic than is the case for certain fish species. However, invertebrate groups are poorly known on the slope reefs, and additional data are required from diverse habitats to evaluate habitat associations and allow comparisons with other ecosystems.

It is clear that the continental slope of the southeast region is important for corals and biodiversity. This is evidenced from the numerous new coral habitats discovered, the wide ranging extent and diversity of corals, numerous species from a variety of taxa newly recorded for the area, the many species new to science, and the fact that more fishes were recorded around these banks than any other deep-coral habitats worldwide. Some corals also provide important scientific data that will increase our understanding of climate and oceanographic changes. Some corals and/or associated fauna (e.g., sponges) may have significant biomedical value. The overall impact of biodiversity in marine systems is significant (Worm et al. 2006), and while biodiversity of southeastern U.S. deep-coral systems is still poorly documented, these ecosystems are obviously a major component of regional slope ecology. Their protection, coupled with ongoing research, is necessary.

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Appendix 6.1. Checklist of deep corals occurring off the southeastern United States (Cape Hatteras, NC to Key Biscayne, FL) at 200-1000 m depth (except shallower *Oculina*). Higher taxa are in phylogenetic order; families, genera and species are in alphabetical order. Some species have cosmopolitan distributions; however, only the northwestern Atlantic portion of their geographic ranges are reported. MR = museum records (holdings of the National Museum of Natural History, Smithsonian Institution). C & B = Cairns & Bayer (2002, 2003, 2004a, 2004b) *** = Cairns (1979, 2000), Cairns et al. 1999, Cairns & Chapman 2001, unpublished records. S = azooxanthellate solitary scleractinian corals. State of knowledge for the solitary corals is limited; therefore, species-specific geographic and bathymetric ranges are not given. Species included in this list have either been reported from the southeastern U.S. or are likely to occur in the region based on Cairns (1979, 2000), Cairns et al. 1999, and data obtained from unpublished records.

Higher Taxon	Species	Distribution	Depth Range(m)	Reference
Phylum Cnidaria				
Class Anthozoa				
Subclass Hexacorallia				
Order Scleractinia				
Family Anthemiphylliidae	*Anthemiphyllia patera* Pourtalès, 1878			S
Family Caryophylliidae	*Anomocora fecunda* (Pourtalès, 1871)			S
	Asterosmilia marchadi (Chevalier, 1966)			S
	Asterosmilia prolifera (Pourtalès, 1871)			S
	Caryophyllia ambrosia caribbeana Cairns, 1979			S
	Caryophyllia antillarum Pourtalès, 1874			S
	Caryophyllia berteriana Duchassing, 1850			S
	Caryophyllia polygona Pourtalès, 1878			S
	Cladocora debilis Milne Edwards & Haime, 1849			S
	Concentrotheca laevigata (Pourtalès, 1871)			S
	Crispatotrochus squiresi (Cairns, 1979)			S
	Dasmosmilia lymani (Pourtalès, 1871)			S
	Deltocyathus agassizii Pourtalès, 1867			S
	Deltocyathus calcar Pourtalès, 1874			S
	Deltocyathus eccentricus Cairns, 1979			S
	Deltocyathus italicus (Michilotti, 1838)			S
	Deltocyathus moseleyi Cairns, 1979			S
	Deltocyathus pourtalesi Cairns, 1979			S

Higher Taxon	Species	Distribution	Depth Range	Reference
	Desmophyllum dianthus (Esper, 1794)			S
	Labyrinthocyathus facetus Cairns, 1979			S
	Labyrinthocyathus langae Cairns, 1979			S
	Lophelia pertusa (Linnaeus, 1758)	Nova Scotia - FL Straits; eastern Gulf of Mexico; Lesser Antilles	95-2000; commonly 500-800	***
	Oxysmilia rotundifolia (Milne Edwards & Haime, 1848)			S
	Paracyathus pulchellus (Philippi, 1842)			S
	Premocyathus cornuformis (Pourtalès, 1868)			S
	Solenosmilia variabilis Duncan, 1873	GA - Suriname	220-1383	***
	Stephanocyathus coronatus (Pourtalès, 1867)			S
	Stephanocyathus diadema (Moseley, 1876)			S
	Stephanocyathus laevifundus Cairns, 1977			S
	Stephanocyathus paliferus Cairns, 1977			S
	Tethocyathus cylindraceus (Pourtalès, 1868)			S
	Tethocyathus recurvatus (Pourtalès, 1878)			S
	Tethocyathus variabilis Cairns, 1979			S
	Trochocyathus rawsonii Pourtalès, 1874			S
Family Dendrophylliidae	*Balanophyllia cyathoides* (Pourtalès, 1871)			S
	Balanophyllia floridana Pourtalès, 1868			S
	Bathypsammia fallosocialis Squires, 1959			S
	Bathypsammia tintinnabulum (Pourtalès, 1868)			S
	Cladopsammia manuelensis (Chevalier, 1966)	Straits of FL; northern Gulf of Mexico; Arrowsmith Bank, Yucatan	55-366	***
	Eguchipsammia gaditana (Duncan, 1873)	NC, GA; Arrowsmith Bank, Yucatan	146-505	***
	Enallopsammia profunda (Pourtalès, 1867)	MA - Straits of Florida	403-1748	***
	Enallopsammia rostrata (Pourtalès, 1878)	GA; off Nicaragua	300-1646	***

Higher Taxon	Species	Distribution	Depth Range	Reference
	Thecopsammia socialis Pourtalès, 1868			S
Family Flabellidae	*Flabellum atlanticum* Cairns, 1979			S
	Flabellum moseleyi Pourtalès, 1880			S
	Javania cailleti (Duchassaing & Michelotti, 1864)			S
	Polymyces fragilis (Pourtalès, 1868)			S
Family Fungiacyathidae	*Fungiacyathus symmetricus* (Pourtalès, 1871)			S
Family Guyniidae	*Pourtalocyathus hispidus* (Pourtalès, 1878)			S
	Schizocyathus fissilis Pourtalès, 1874			S
	Stenocyathus vermiformis (Pourtalès, 1868)			S
Family Oculinidae	*Madrepora carolina* (Pourtalès, 1871)	NC - FL; Greater Antilles; western Caribbean; Gulf of Mexico	53-801; commonly 200-300	***
	Madrepora oculata Linnaeus, 1758	GA - Rio de Janeiro, Brazil; Gulf of Mexico	144-1391	***
	Oculina varicosa Lesueur, 1821	NC - FL; West Indies; Bermuda	3-150	***
Family Pocilloporidae	*Madracis myriaster* (Milne Edwards & Haime, 1849)	GA - Suriname; throughout the Caribbean and Gulf of Mexico	20-1220	***
Family Turbinoliidae	*Cryptotrochus carolinensis* Cairns, 1988			S
	Deltocyathoides stimpsonii (Pourtalès, 1871)			S
Order Antipatharia				
Family Leiopathidae	*Leiopathes glaberrima* (Esper, 1788)	GA; FL; Gulf of Mexico (FL;AL; LA); Jamaica; Campeche Bank, Mexico; Venezuela	37; 220-685	20 MR; Ross et al. unpub.
	Leiopathes spp.			
Family Schizopathidae	*Bathypathes alternata* Brook, 1889	SC; GA; FL; Yucatan Channel (off Arrowsmith Bank)	412-658	3 MR; Ross et al. unpub.
	Parantipathes sp.			
Order Zoanthidae				
Family Gerardiidae	*Gerardia* spp.			

Higher Taxon	Species	Distribution	Depth Range	Reference
Subclass Octocorallia				
Order Alcyonacea				
Family Alcyoniidae	*Anthomastus agassizi* Verrill, 1922	Canada (Nova Scotia, Newfoundland); MA; DE; GA; FL; Bahamas	320-3186	28 MR; Ross et al. unpub.
	Anthomastus grandiflorus Verrill, 1878	Canada (off Nova Scotia, Newfoundland); MA; VA; NC	137-457; 750-2919	41 MR
	Bellonella rubistella (Deichmann, 1936)	FL; Bahamas; Colombia; Venezuela; Trinidad; Tobago; Suriname; Dominican Republic; St. Lucia	24-329	25 MR
Family Clavulariidae	*Clavularia modesta* (Verrill, 1874)	Canada (off Nova Scotia, Newfoundland); ME; MA; SC; GA; FL	29-861	63 MR
	Scleranthelia rugosa (Pourtalès, 1867)	SC; Bahamas; Dominican Republic; Martinique	175-586	9 MR
	Telesto fruticulosa Dana, 1846	NC; SC; GA; FL	13-105	218 MR
	Telesto nelleae Bayer, 1961	NC; Straits of FL (off Havana, Cuba); Bahamas	27-298; 1023-1153	19 MR
	Telesto sanguinea Deichmann, 1936	SC; FL; Gulf of Mexico (off FL, LA)	24-134	44 MR
	Trachythela rudis Verrill, 1922	FL	805	1 MR
Family Nephtheidae	*Gersemia fruticosa* (Sars, 1890)	Canada (off Nova Scotia, Newfoundland); MA; DE; VA; FL	91-368; 770; 2107-3506	42 MR
	Pseudodrifa nigra (Pourtalès, 1868)	SC; GA; FL; Bahamas; Straits of FL (off FL Keys; Havana, Cuba); Gulf of Mexico (off FL Keys)	60-878; 1153-1023	47 MR; Ross et al. unpub.
Family Nidaliidae	*Siphonogorgia agassizii* (Deichmann, 1936)	FL; Gulf of Mexico (FL; TX)	14-159; 350-400	27 MR
Order Gorgonacea				
Family Chrysogorgiidae	*Chrysogorgia multiflora* Deichmann, 1936	GA; FL; Bahamas; Straits of FL (off Key West); Gulf of Mexico (FL Keys); Lesser Antilles; Brazil	320-1354	Cairns, 2001b; 14 MR
	Chrysogorgia squamata (Verrill,1883)	Jacksonville, Fl; Caribbean	430-1050	Ross et al. unpub.

Higher Taxon	Species	Distribution	Depth Range	Reference
Family Coralliidae	*Corallium* sp.			
	Corallium niobe Bayer, 1964	off Jupiter Inlet; Bahamas	659-677; 1023	3 MR
Family Gorgoniidae	*Eunicella modesta* (Verrill, 1883)	Savannah lithoherms, GA; east coast FL *Lophelia* reefs	518-732	Reed 2004; Ross et al. unpub.
Family Isididae	*Acanella eburnea* (Pourtalès, 1868)	Hudson Canyon; SC; FL; Bahamas; Gulf of Mexico (FL; LA; TX); Caribbean Sea (Nevis)	309-2100	34 MR
	Keratoisis flexibilis (Pourtalès, 1868)	GA; FL; eastern Gulf of Mexico; Bahamas; Campeche Bank, Mexico; Guadeloupe; Colombia; Venezuela	170-878	29 MR
	Keratoisis ornata Verrill, 1878	Canada (off Nova Scotia, Newfoundland); MA; GA; FL; Bahamas; Cuba	274-3236	45 MR; Ross et al. unpub.
	Lepidisis longiflora Verrill, 1883	FL; Caribbean Sea (Nevis)	743-1125	2 MR
Family Paragorgiidae	*Paragorgia arborea* (Linnaeus, 1782)	Canada; MA; NJ; MD; VA; NC	247-680	9 MR
	Paragorgia johnsoni Gray, 1862	Florida Straits (off Palm Beach); Bahamas	522-608	6 MR
Family Plexauridae	*Paramuricea placomus* (Linnaeus, 1758)	Canada (off Nova Scotia); GA; FL; Straits of FL (off Havana, Cuba)	247-805	6 MR
	Paramuricea sp.			
	Swiftia casta (Verrill, 1883)	MA; SC; GA; FL; Straits of FL (off FL Keys; Havana, Cuba); Bahamas; Gulf of Mexico (FL; LA); Yucatan Channel (off Arrowsmith Bank)	40-1953	49 MR
	Swiftia exserta (Ellis & Solander, 1786)	GA; FL; Straits of FL (off FL Keys); Bahamas; Puerto Rico; Gulf of Mexico (FL; MS); Mexico; Panama; Colombia; Venezuela; Tobago; French Guiana; Guyana; Brazil	18-494	54 MR

Higher Taxon	Species	Distribution	Depth Range	Reference
Family Primnoidae	*Swiftia koreni* (Wright & Studer, 1889)	Lydonia Canyon; FL; Gulf of Mexico (off FL Keys)	221-858	3 MR
	Callogorgia americana americana Cairns & Bayer, 2002	Straits of Florida; Lesser Antilles	183-732	C & B, 2002
	Callogorgia gracilis (Milne Edwards & Haime, 1857)	off central Florida; Bahamas; Antilles; off Honduras; northern Gulf of Mexico	82-514	C & B, 2002
	Calyptrophora gerdae Bayer, 2001	Straits of FL	229-556	Bayer, 2001
	Calyptrophora trilepis (Pourtalès, 1868)	SC; GA; Bahamas	593-911	Bayer, 2001; 8 MR
	Candidella imbricata (Johnson, 1862)	New England seamounts; Bermuda; eastern coast FL; Bahamas; Antilles; northern Gulf of Mexico	514-2063	C & B, 2004b
	Narella bellissima (Kukenthal, 1915)	Straits of FL (off Delray Beach); Bahamas; Lesser Antilles	161-792	C & B, 2003
	Narella pauciflora Deichmann, 1936	Straits of FL (off Delray Beach); Bahamas; Cuba; Puerto Rico; Campeche Bank, Mexico	738-1473	C & B, 2003
	Narella versluysi (Hickson, 1909)	Bermuda; Straits of FL (off St. Lucie Inlet, Palm Beach, Delray Beach;Bahamas); Cuba	677-900	C & B, 2003
	Paracalyptrophora duplex Cairns & Bayer, 2004	Straits of FL (off Cape Canaveral - Cuba); Bahamas; Lesser Antilles	374-555	C & B, 2004a
	Paracalyptrophora simplex Cairns & Bayer, 2004	Insular side Straits of FL (off Palm Beach, north of Little Bahama Bank), Bahamas to Yucatan Channel	165-706	C & B, 2004a
	Plumarella aurea (Deichmann, 1936)	off SC to Cuba	310-878	C & B, 2004b
	Plumarella dichotoma Cairns & Bayer, 2004	off SC to FL	494-1065	C & B, 2004b
	Plumarella laxiramosa Cairns & Bayer, 2004	off North and South Carolina	348-572	C & B, 2004b

Higher Taxon	Species	Distribution	Depth Range	Reference
	Plumarella pellucida Cairns & Bayer, 2004	off NC, through Straits of FL; Bahamas	549-1160	C & B, 2004b
	Plumarella pourtalesii (Verrill, 1883)	off NC, through Straits of FL; Cuba; Bahamas	183-882	C & B, 2004b
	Thouarella bipinnata Cairns, 2006	off northern FL; Straits of FL; off Little Bahama Bank; off Guyana	507-1000	Cairns, 2006; Ross et al. unpub.
Order Pennatulacea				
Family Kophobelemnidae	*Kophobelemnon sertum* Verrill, 1885	off NC	1542	1 MR
Class Hydrozoa				
Order Anthoathecatae				
Suborder Filifera				
Family Stylasteridae	*Crypthelia floridana* Cairns,1986	eastern, southwestern FL	593-823	Cairns, 1986
	Distichopora foliacea Pourtalès, 1868	GA; Straits of FL (off FL Keys); SE Gulf of Mexico; Yucatan Channel (off Arrowsmith Bank)	183-527	Cairns, 1986
	Pliobothrus symmetricus Pourtalès, 1868	SC through Lesser Antilles	73-922; commonly 150-400	Cairns, 1986
	Stylaster complanatus Pourtalès, 1867	GA; Bahamas; Yucatan Peninsula; Virgin Islands	183-707	Cairns, 1986
	Stylaster erubescens Pourtalès, 1868	SC - SW FL; Bahamas; Cay Sal Bank; Yucatan Channel (off Arrowsmith Bank)	146-965; commonly 650-850	Cairns, 1986
	Stylaster laevigatus Cairns, 1986	SC; Bahamas; Cuba; Yucatan Channel (off Arrowsmith Bank)	123-759; commonly 300-400	Cairns, 1986
	Stylaster miniatus (Pourtalès, 1868)	SC; Straits of FL (off FL Keys); Bahamas; Cuba	146-530	Cairns, 1986

STATE OF DEEP CORAL ECOSYSTEMS IN THE GULF OF MEXICO REGION: TEXAS TO THE FLORIDA STRAITS

Sandra Brooke[1] and William W. Schroeder[2]

I. INTRODUCTION

This report provides a summary of the current state of knowledge of deep (defined as >50 m) coral communities that occur on hard-bottom habitats in the Gulf of Mexico region, For the purposes of this report, the Gulf of Mexico region includes the waters within the U.S. exclusive economic zone (EEZ) of Texas, Louisiana, Mississippi, Alabama, and Florida as far north as Biscayne Bay on the East Coast (Figure 7.1), which includes the Pourtales Terrace and part of the Miami Terrace. The spatial distribution of deep coral species and their associated fauna are placed in the context of the geology and hydrography of three sub-regions, all of which have extensive deep coral communities, but with very different biological structure. The sub-regions are: (1) the northern Gulf of Mexico (2) the west Florida shelf and slope, and (3) the Florida Straits. The structure of the report follows the primary hydrographic flow from west to east through the Gulf of Mexico and into the Florida Straits. Threats affecting these communities, management and conservation concerns, and research needs are also discussed.

The most extensively documented coral habitats in the Gulf of Mexico are within the Flower Garden Banks National Marine Sanctuary (FGBNMS), which is located approximately 160 km south of the Texas/Louisiana border. Since the inception of the sanctuary, most of the research has been focused on communities within SCUBA depths at the East and West Flower Garden Banks and Stetson Bank. Over the past few years however, investigation into the deeper habitats on the shelf, both within and outside the sanctuary boundaries, has expanded knowledge of the biological communities that are found below SCUBA depth limits. Extensive high-resolution multibeam mapping surveys have been conducted by NOAA, MMS and USGS, on select reefs and banks in the region (http://walrus.wr.usgs.gov/pacmaps/wg-index.html), and this information has facilitated focused ROV and manned submersible operations.

The deep shelf and slope regions of the northern Gulf of Mexico have been extensively mapped and surveyed during exploration for oil and gas deposits, which led to the discovery and subsequent research on chemosynthetic communities associated with hydrocarbon seepage. The substrate in the deep Gulf of Mexico is principally comprised of fine particulates; however, large amounts of authigenic carbonate deposits are precipitated from biogeochemical activity associated with hydrocarbon fluid seepage (Schroeder 1992). Authigenic carbonates provide hard substrate for a wide variety of benthic fauna, including the structure-forming scleractinian, *Lophelia pertusa.* In 1955, Moore and Bullis collected large quantities of *L. pertusa (=prolifera)* in 420 to 512 m of water from the northeastern continental slope approximately 74 km east of the Mississippi River delta (Moore and Bullis,1960). More recently, reports of living *L. pertusa* in the Gulf of Mexico are available from publications (Cairns 1979, 2000, Cairns and Viada 1987, McDonald et al. 1989, Schroeder 2002, Schroeder et al. 2005), and records from the National Museum of Natural History Taxonomic Database. Recent research expeditions conducted between 2000-2004 (funded by NOAA's office of Ocean Exploration and the Minerals Management Service) represent some of the first scientific submersible and remotely operated vehicle (ROV) dives in these areas, and they provide considerable new information on the distribution, habitat and biodiversity of deep coral communities in the Gulf of Mexico (Continental Shelf Associates, in review)

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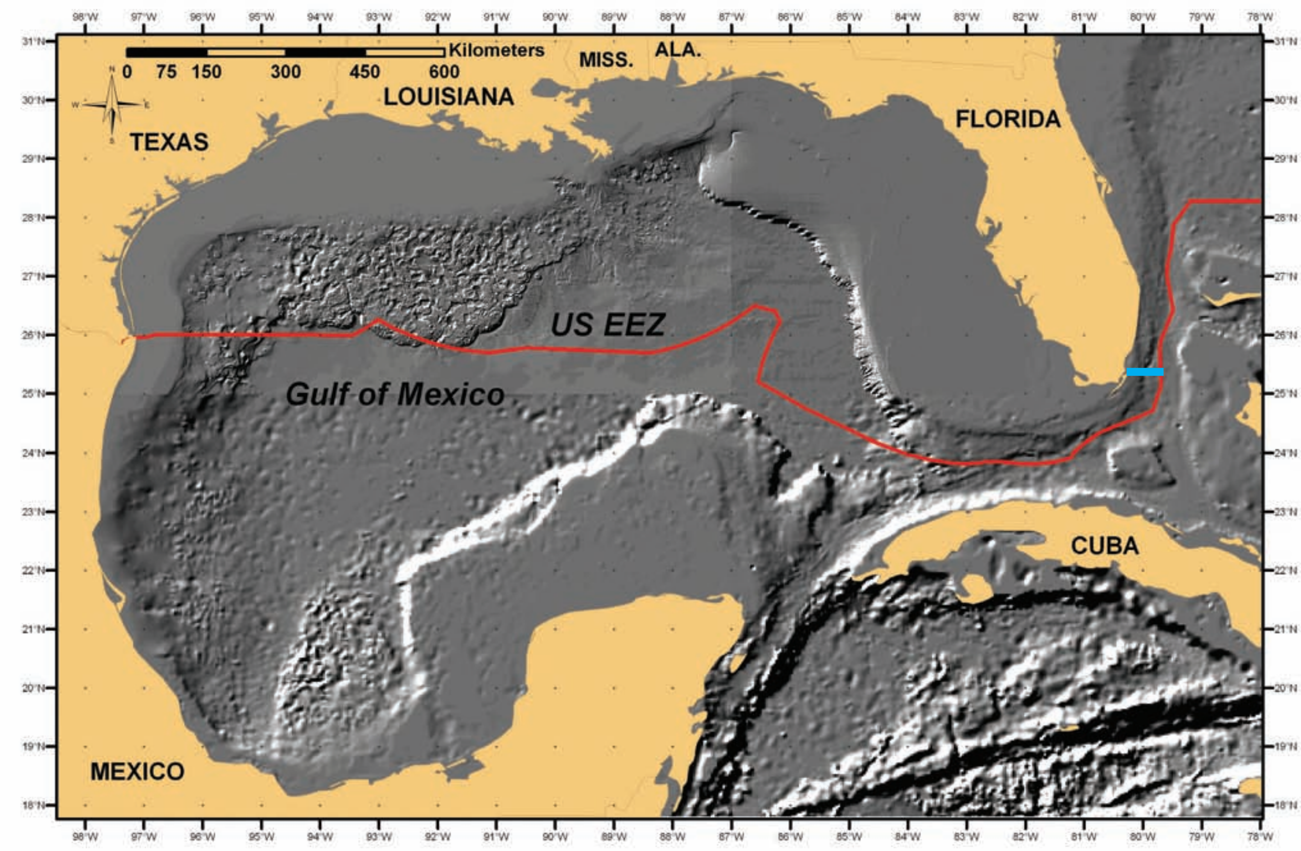

Figure 7.1 Map of the Gulf of Mexico and Florida, showing the Exclusive Economic Zone (EEZ) boundary. The Gulf of Mexico regional chapter covers deep water coral habitat enclosed by the red EEZ boundary and does not extend beyond the blue line. Map credit: Flower Garden Banks National Marine Sanctuary (FGBNMS)

Little is known about the ecology of the west Florida slope, although Collard and D'Asaro (1973) documented many benthic invertebrates of the eastern Gulf of Mexico from extensive dredging surveys, and Cairns (1978) compiled a comprehensive list of ahermatypic scleractinia for the entire Gulf of Mexico. Almost a decade later, Newton et al. (1987) described the coral mounds of the west Florida slope at depths of 500m. They found *L. pertusa, Madrepora oculata* and *Bathypsammia sp,* but none of their coral samples were living. More recent exploration of this area by Reed et al. (2004, 2005b, 2006b) has expanded our descriptive knowledge of the fauna, but ecological questions remain unanswered.

Near the western end of the Straits of Florida, the Tortugas and Agassiz Valleys exhibit hard-bottom habitats and high-relief escarpments at depths of 512-1,189 m (Minter et al. 1975). Deep, hard substrates may also exist in 500-1000 m depths on the Tortugas Terrace, 80 km west of the Dry Tortugas (Uchupi, 1968), but the fauna of these areas have not been explored. In the southern Straits of Florida and at the southern end of the Florida carbonate platform, the Pourtales Terrace provides extensive, high-relief, hard bottom habitat, at depths of 200-450 m. Louis de Pourtales discovered the feature in 1867 during a survey aboard the U.S. Coast Survey ship *Bibb* to lay a telegraph cable from Key West to Havana (Jordan et al., 1964). Alexander Agassiz (1888) named this feature the Pourtales Platform, and Jordan and Stewart (1961) later renamed it the Pourtales Terrace. Jordan (1964) discovered large sinkholes on the Pourtales Terrace. Land and Paull (2000) mapped and described nine of these sinkholes using side-scan sonar, seismic profiler, and echo-sounder profilers aboard the U.S. Navy's submersible NR-1. Reed et al. (2005) also described the fish and invertebrate communities associated with high-relief deep-water structures and deep-water sinkholes on the Pourtales Terrace using the *Johnson Sea-Link* submersible.

II. GEOLOGICAL SETTING

The Gulf of Mexico basin consists of many different topographic features. The continental shelf slopes gradually to depths between 100 and 200 m. The widest point is off southern Florida (about 300 km wide) and narrowest is at the Mississippi Delta (10 km). The continental shelf off west Florida and the Yucatan are carbonate with some complex topographic features; the eastern Gulf of Mexico and Texas-Louisiana shelves are primarily composed of terrigenous sediments. In the northern Gulf of Mexico, the Mississippi and Bryant submarine fans and the flat Sigsbee Abyssal Plain give way to the complex slump structure of the East Mexican Slope and the extremely complex topography of the Texas/Louisiana continental slope (Rowe and Kennicutt 2001). This section briefly describes the geology of each region to provide context for the more detailed description of their biological communities.

Northern Gulf of Mexico

The middle and outer portions of the Texas/Louisiana shelf are scattered with intermittent banks of various depths and shape. These are usually comprised of carbonates, with silt and clay, overlying raised salt diaper structures (Rezak et al. 1985). These banks all support hard bottom communities, with different levels of complexity, but the most well known and ecologically well developed are the Flower Gardens Banks, which are situated on top of salt domes rising from approximately 130 m to 20 m depth (Figure 7.2). Salt domes began to form 160-170 million years ago when salt layers were deposited in what was then a shallow sea, and subject to evaporation. In subsequent years, deep layers of sediments were deposited over the salt layers. Eventually, internal pressures became great enough to push isolated pockets of salt up through the sediments, forcing the seafloor to bulge upward in distinct domes. The Flower Gardens coral reef communities began developing on top of the domes 10,000 to 15,000 years ago and have now overgrown the bedrock on which they developed.

The continental slope off Texas, Louisiana, and portions of Mississippi is geologically and physiographically one of the most complex in the world. Over ninety basins and seven submarine canyons dissect the continental margin of the northwestern Gulf of Mexico. Major portions of the middle and lower slope appear to be devoid of gas seeps, while the upper slope contains salt diapiric structures (such as mud and gas mounds), fluid expulsion features, hard-grounds, erosional gullies, numerous gas seeps and gas hydrate deposits. Deposits of authigenic carbonate, produced as a byproduct of chemosynthetic activity, provide hard substrate for development of sessile benthic communities, many of which are coral-dominated (Figures 7.3a, b). Eroded into the complex topography of the Texas/Louisiana slope, are four major canyon systems: the Mississippi, Keathley, Bryant, and Alaminos Canyon (Rowe and Kennicutt 2001). In the eastern portion of the region, sediments

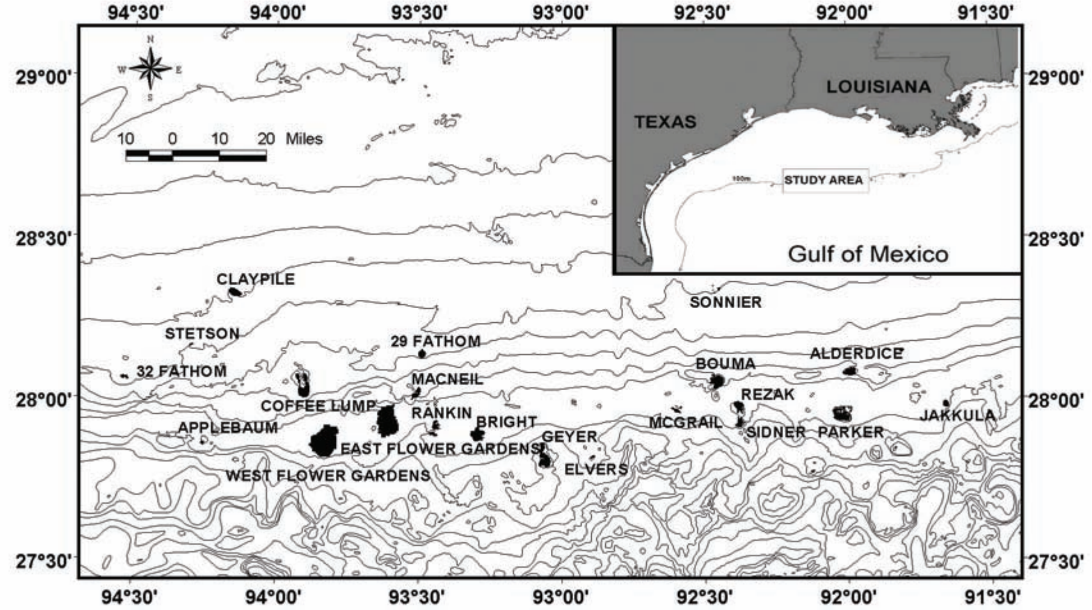

Figure 7.2. Map of the Flower Gardens area showing the location of the many reefs and banks in this area. Map credit: Resek et al. 1985.

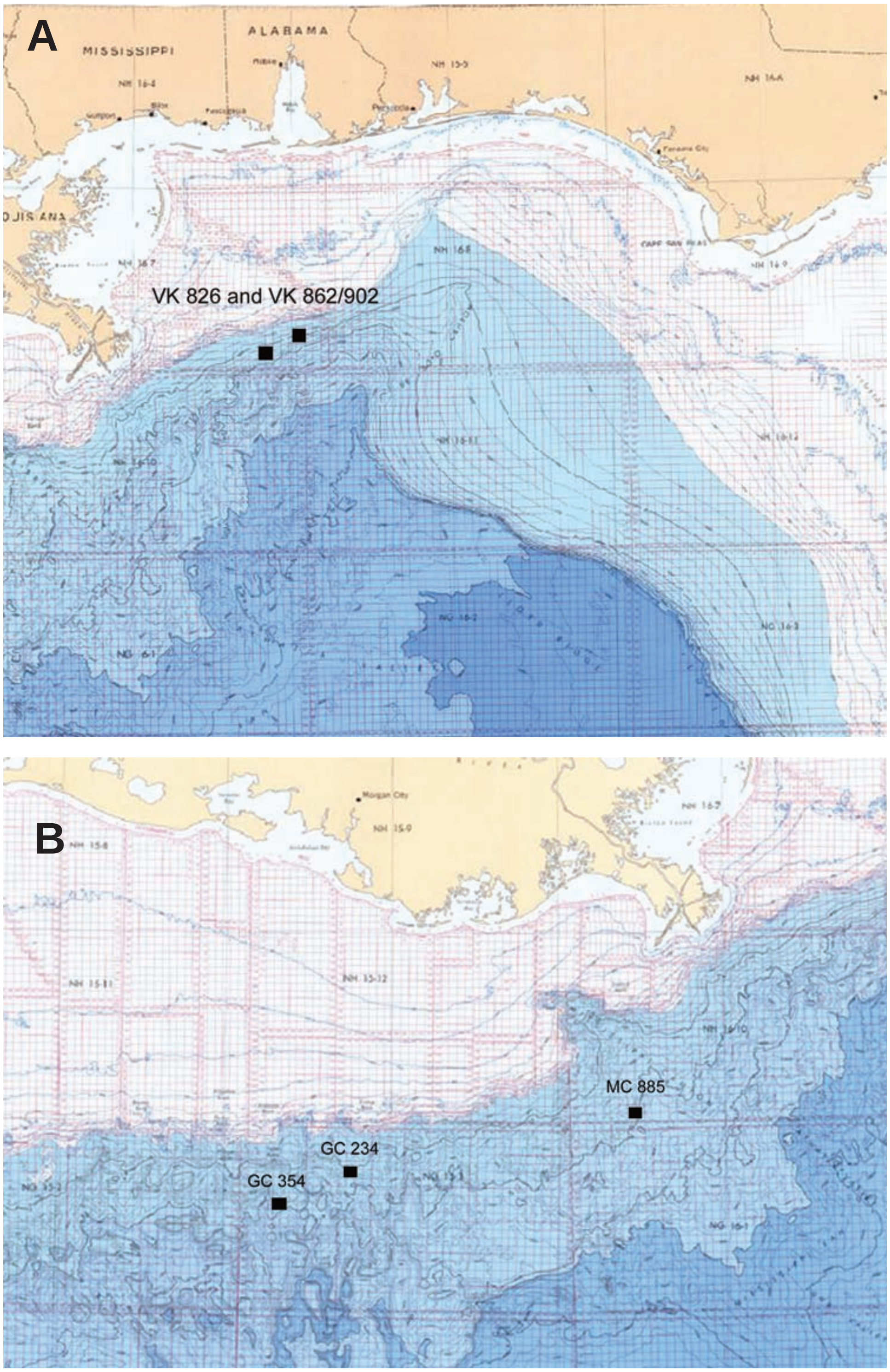

Figure 7.3. Bathymetric map of the Gulf of Mexico showing known areas of abundant coral habitat. Chart from NOAA, NOS Bathymetric maps 1986. Scale 1:100,000. A) Viosca Knoll sites: dense *L. pertusa* and other coral colonies at both VK826 and VK862/906. Map credit: OIMB for the U.S. Minerals Management Service (MMS).
B) Mississippi Canyon and Green Canyon sites: MC885 is comprised of large fields of *C. americana delta* and the Green Canyon sites support well developed *L. pertusa*. Map credit: OIMB for MMS.

from the Mississippi cover the western edge of the Florida shelf and a transition towards carbonate sediments begins. The Florida escarpment separates the Florida shelf from the Gulf Basin and also forms the southeastern side of the Desoto Canyon. In a region of high sediment deposition, the presence of the Desoto Canyon is poorly understood (Gore 1992). Some theories suggest that the canyon is the result of erosion caused by oceanic currents, possibly the Loop Current (Nowlin 1971).

West Florida shelf and slope

The west Florida shelf is a gently sloping (1-2^{o}) broad carbonate platform that extends 750 km from Desoto Canyon in the north to the western Straits of Florida (Holmes, 1981). Along the edge of the west Florida shelf there is a series of “drowned reefs” or fossil reefs” at water depths ranging from approximately 50 m to over 120 m. In the northern region, small areas of the shelf have been designated as protected areas (Madison Swanson, Steamboat Lumps) by

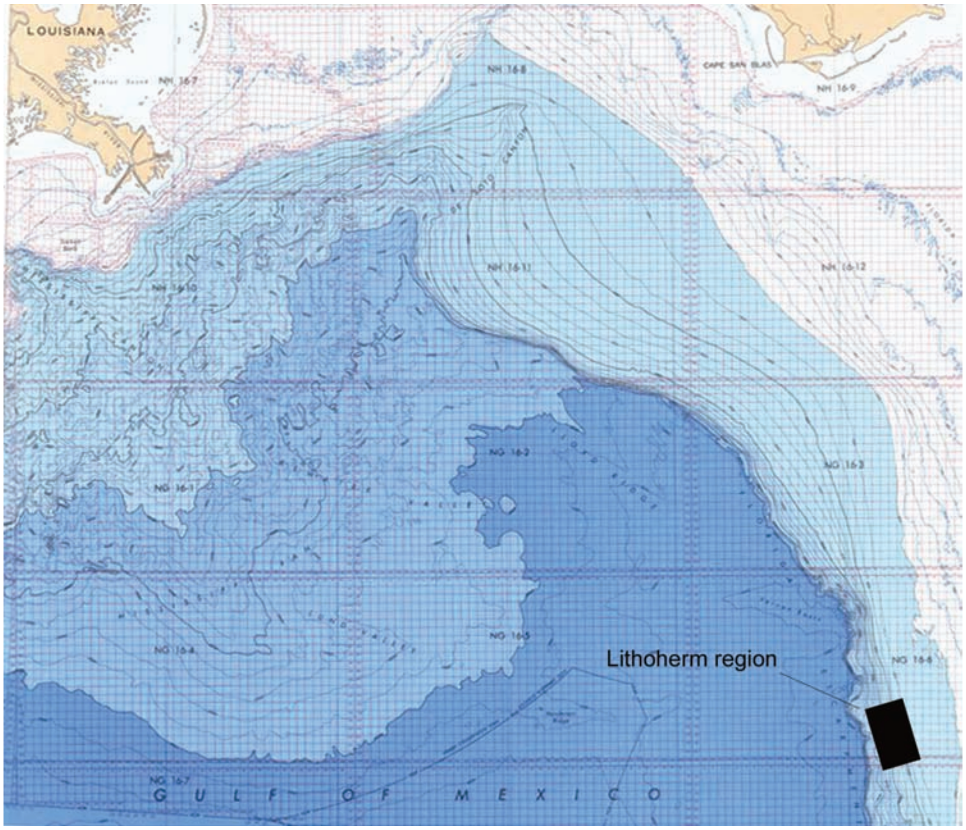

Figure 7.4a. Map of the eastern Gulf of Mexico showing the location of *Lophelia* lithoherms on the southwest Florida Slope (Reed et al. 2006). Scale 1:100,000. Map credit: NOAA, NOS Bathymetric maps 1986.

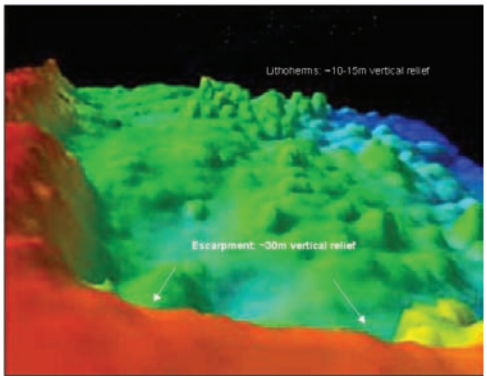

Figure 7.4b. Seabeam image of a southward view of the SW Florida Slope lithoherms (x2 vertical exaggeration). Image credit: Reed et al. and NOAA-OE.

the National Marine Fisheries Service (NMFS) on the recommendation of the Gulf of Mexico Fisheries Management Council (GMFMC) to preserve declining reef fish populations. on the southwest shelf edge, the shallowest of these ancient reefs, is Pulley Ridge, which is approximately 200 km long and supports well-developed communities of zooxanthellate scleractinian plate corals and other hard-bottom fauna at depths of 60-70 m. This area has been protected from bottom fishing to protect the fragile benthos, which is currently the deepest known hermatypic reef complex in U.S. Atlantic waters. Seaward of the shelf, at the 500m isobath on the southwest Florida slope is a 20 km long zone of high-relief (10–15 m) Pleistocene coral mounds (Figure 7.4a). This region was first recognized from high resolution seismic reflection profiles during a cruise on the *R/V Cape Hatteras* in 1984 and consists of dozens and possibly hundreds of lithoherms (Figure 7.4b) composed of rugged black phosphorite-coated limestone boulders and outcrops (10- 15 m in height), some of which are capped with thickets of *Lophelia* coral (Newton et al. 1987, Reed et al. 2004, Reed et al. 2006b). A deepwater sinkhole (200m) has also been described in detail from submersible dives off the west Florida shelf (Reed et al. 2005b). The Florida slope then grades into the Florida Escarpment, which extends from depths of 2500–3280 m into the eastern Gulf of Mexico. The face of the escarpment has steep vertical limestone cliffs of Cretaceous age, with intervening sediment-covered planes that provide habitat for dense chemosynthetic communities (Paull and Neumann 1987, Paull et al. 1990, 1991).

Florida Straits

Two Miocene-age terraces, the Miami Terrace and Pourtales Terrace, occur off southeastern Florida and the Florida Keys reef tract. The Pourtales Terrace is a large triangular area over 213 km in length that runs parallel to the Florida Keys (Figure

7.5). The terrace is the drowned southern end of the Florida carbonate platform covering 3,429 km^2 at depths of 200-450 m. The terrace provides extensive, high-relief, hard-bottom habitat with as much as 120 m vertical relief. The eastern section is comprised of a band of irregular topography and has the greatest relief on the terrace. The central section is flat with no topographic features. The southwest margin of the terrace contains a series of sinkholes that extend for approximately 100 km off the lower Florida Keys (Jordan and Stewart 1961, Jordan et al. 1964, Land and Paull 2000). One of these, the Jordan Sinkhole, has a vertical relief of 206 m and may be one of the deepest and largest sinkholes known. The Jordan and Marathon sinkholes were described in detail from submersible dives by Reed et al. (2005b). The middle and eastern portion of the Pourtales Terrace consists of a northeasterly band of karst-like topography, with depressions, flanked by knolls and ridges that extend up to 91 m above the terrace (Jordan et al. 1964, Land and Paull 2000). Further to the northeast is another zone of 40m high topographic relief that lacks any regular pattern (Gomberg 1976, Reed 2004). There are many high-relief bioherms (up to 120 m vertical relief) in this area, including a region called "The Humps" by local fishers, which is approximately 26 km south of Alligator and Tennessee Reefs in the Florida Keys (Reed 2004, Reed et al. 2005b).

III. OCEANOGRAPHIC SETTING

The Gulf of Mexico is a semi-closed basin of approximately 1.5 million km^2 with the continental shelves surrounding a deep abyss with maximum depths of approximately 3400 m in the eastern portion and 3700 m in the western portion. The surface waters of the Gulf of Mexico have been studied in great detail, but there is comparatively little information on circulation below 1000 m. Direct current measurements were rare (e. g., Pequegnat 1972, Hamilton 1990) until recently (Inoue et al. 2002, Hamilton and Lugo-Fernandez 2001). The dominant hydrographic feature in the Gulf of Mexico is the Loop Current, which is formed when the Yucatan Current intrudes northward into the Gulf of Mexico from the Caribbean, flows clockwise around the basin, and empties into the Straits of Florida.

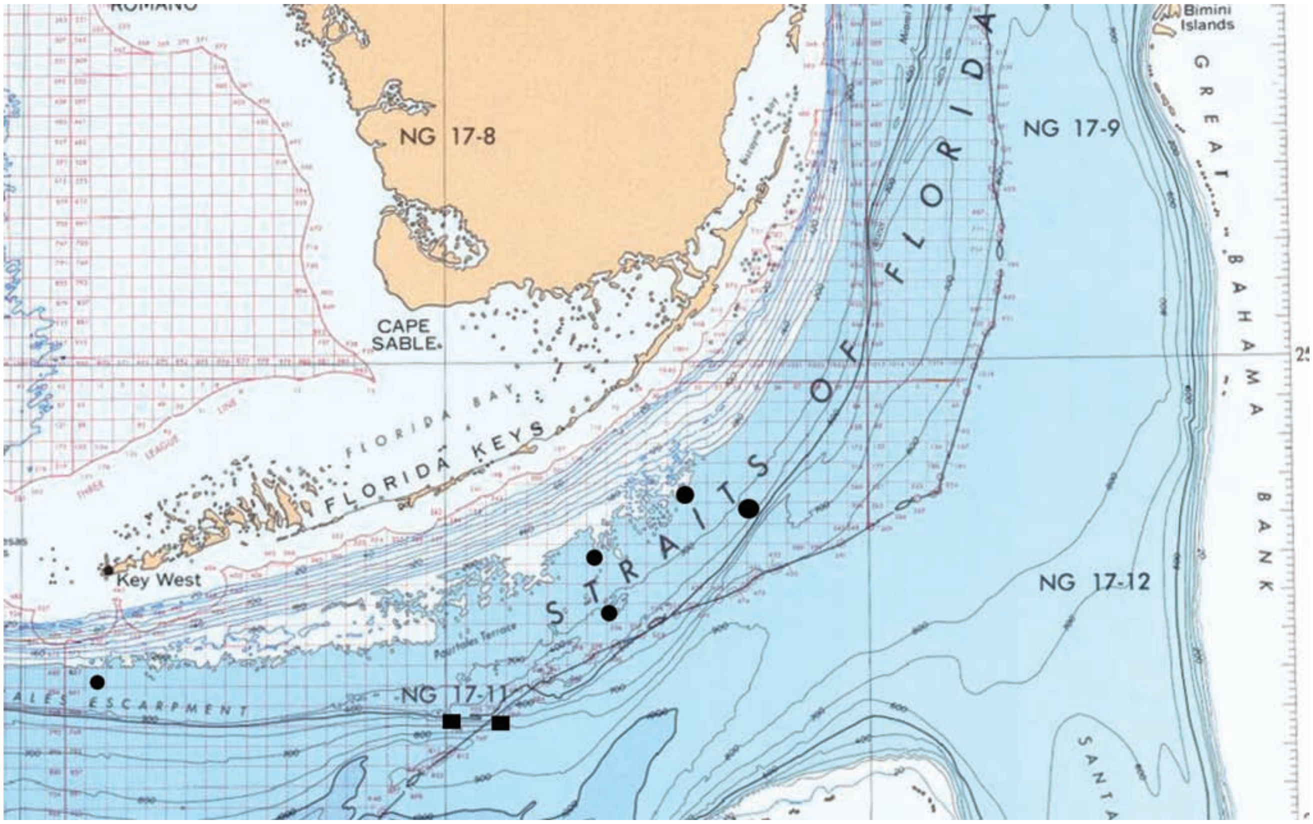

Figure 7.5. Chart of the Straits of Florida showing the Pourtales Terrace. The lithoherms are marked with black circles and the Jordan and Marathon sinkholes with black squares.(from Land and Paull 2000, Reed 2005b). Scale 1: 100,000. Map credit: NOAA, NOS Bathymetric maps 1986.

Northern Gulf of Mexico
While the Loop Current and associated rings are the major energetic currents in the Gulf of Mexico, creating extremely complex shelf and slope circulatory patterns, several other classes of energetic currents have also been observed in the deep waters of the Gulf (Bryant et al. 2000). Data collected in 1999 using the Texas A&M University (TAMU) deep-tow seismic system showed evidence of a large field of sedimentary furrows running along the base of the Sigsbee Escarpment in the Bryant Canyon area of the northwestern Gulf of Mexico (Bryant et al. 2000). Submarine furrows have been previously observed along the Blake Bahama Outer Ridge, the Bermuda Rise, the Brazilian Margin, and several other localities (see review by Flood, 1983), but the huge extent of the furrows observed in the northwestern Gulf of Mexico is unprecedented. Near-bottom current meters deployed near the base of the Sigsbee Escarpment (1978 m) have recorded flow events with velocities of more than 85 cm s^{-1} at 2000m (Hamilton and Lugo-Fernandez, 2001), during loop current eddy shedding. The effect of these strong deepwater flows on slope and shelf currents and their benthic communities is unknown and warrants further research.

West Florida Shelf and Slope
The Loop Current dominates the circulation in the eastern Gulf of Mexico and anticyclonic rings spawned by the Loop Current move west and south (Rowe and Kennicutt 2001). The Loop Current creates a vigorous north-south flow in the eastern Gulf of Mexico and as it migrates laterally over the west Florida shelf, it produces temperature variations at shallow to intermediate depths (50-500m), both seasonally and over longer time scales (Leipper et al. 1972).

Florida Straits
The Loop Current is joined in the Florida Straits by waters passing through the Old Bahama Channel to form the Florida Current, which in turn joins the Antilles Current in the Atlantic to form the Gulf Stream. Currents associated with the Loop Current can extend to great depths in the Florida Straits. High current speeds (>100 cm s^{-1}) were observed at 200 m on the Pourtales Terrace (Reed at al. 2005b). Prior to this observation, lower speeds of 10 cm s^{-1} had been recorded at 500 m depth (Cooper et al. 1990), but these persisted at one location for weeks to months. Strong current events have also been observed below 1000 m, suggesting that the Loop Current and eddies influence the hydrodynamics of the deepest portions of the Gulf of Mexico (Hamilton 1990).

IV. STRUCTURE AND HABITAT-FORMING DEEP CORALS

The Gulf of Mexico has distinct regional differences among faunal communities (Table 7.1). These include hermatypic corals in the shallower (<50 m) salt dome and carbonate shelf habitats, *Lophelia*-dominated communities on the hard substrate of the northern and eastern slope (>200m). Gorgonians and antipatharians are present to various degrees in all habitats but are primary structure-forming coral taxa in parts of the deep slope habitats in the northern Gulf of Mexico, on the shelf between 50-150 m, associated with hardbottom features in and around the reefs and banks, and in parts of the deep slope habitats. Stylasterid hydrocorals are locally abundant on the Florida carbonate shelf and provide some structure but do not form large thickets. Three species of Pennatulacea (sea pens) have been recorded from the northern Gulf of Mexico (National Museum of Natural History (NMNH) database) but do not form significant structural habitat as in some other regions. There are also over 40 species of cup corals present throughout the Gulf of Mexico (Appendix 1), but again, these do not contribute greatly to habitat structure.

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

The dominant azooxanthellate colonial scleractinian coral in the deep (>100m) Gulf of Mexico is *Lophelia pertusa.* Extensive thicket development occurs in the northern Gulf of Mexico, the southwest Florida lithoherms and on parts of the Pourtales and Miami Terraces (Schroeder 2002, Reed et al. 2005b, Reed et al. 2006). The most extensive *L. pertusa* habitat in the northern Gulf of Mexico is situated within the Minerals Management Service lease block Viosca Knoll 826. Further details are given below in the section on spatial distribution of coral species and habitats. The *L. pertusa* colonies found in the Gulf of Mexico exhibit two different morphologies; a heavily calcified thick branching structure which is seen at the Viosca Knoll area and a more fragile form with shorter internodes that is found elsewhere (Figure 7.6). An extensive study of *L. pertusa* habitats in the northern Gulf of Mexico, funded by the Minerals Management Service, was completed in 2005 (Continental Shelf Associates in review). This study addressed various aspects of *L. pertusa* biology and ecology, including *in situ* growth of stained colonies, timing of gametogenesis, tolerance a range of sediment loads and temperatures, and community characterization. The staining experiment showed that *L. pertusa* growth was highly variable (some polyps grew and produced multiple new polyps, but others on the same branch did not grow at all) but on average the linear extension was between 2.4-3.36 mm yr^{-1}. This is slightly lower than published growth data (e.g. average linear extension of 5.5 mm yr^{-1} by Mortensen and Rapp 1998), but was measured for the heavily calcified morphotype, which may be different from the more fragile growth forms. The gametogenic cycle of *L. pertusa* in the Gulf of Mexico is of similar duration to those in the Eastern Atlantic but is offset by several months. In the fjords of Norway, *L. pertusa* spawns in late February/early March and the subsequent gametogenic cycle has already begun before the prior cycle ends (Brooke and Jarnegren unpublished). In the Gulf of Mexico, mature oocytes were found in early September and primary oocytes in November, which indicates that spawning occurs sometime in October (Continental Shelf Associates in review). The causes of the difference in timing of reproduction are unknown and warrant further investigation. Temperature tolerance experiments showed that *L. pertusa* can survive for short periods of time at temperatures as high as 20^{o} C for 24 hours, but long term survival requires a temperature between 10^{o} C and 15^{o} C. This corresponds to published observations that the upper thermal limit of *L. pertusa* distribution is approximately 12^{o} C (Rogers 1999). Sediment experiments conducted in the laboratory (Continental Shelf Associates in review) show that *L. pertusa*

Table 7.1. Structure-forming attributes of deep corals in the Gulf of Mexico region

Taxa	Reef-building	Abundance	Maximum colony size	Morphology	Associations with other structure forming invertebrates	Colony spatial dispersion	Overall rating of structural importance
Lophelia pertusa	Yes	Medium	Large	Branching	Many	Solitary/ Clumped	High
Madrepora oculata	No	Low	Large	Branching	Few	Solitary	Medium
Callogorgia americana delta	No	Medium	Large	Branching	Few/Many	Solitary/ Clumped	Medium
Isididae	No	Medium	Medium/ Large	Branching	Few/Many	Clumped	Medium
Other Alcyonacea	No	Medium	Medium/ Large	Branching	Few/Many	Solitary/ Clumped	Medium
Antipathidae	No	Medium	Large	Branching	Few/Many	Solitary/ Clumped	Medium
Stylasteridae	No	High (Florida Straits)	Small	Branching	Many	Solitary/ Clumped	High (Florida Straits)

Table Key

Attribute	Measure
Reef-Building	Yes/No
Relative Abundance	Low/ Medium/ High
Size (width or height)	Small (<30cm)/ Medium (30cm-1m)/ Large (>1m)
Morphology	Branching/ Non-branching
Associations	None/ Few (1-2)/ Many (>2)
Spatial Dispersion	Solitary/ Clumped
Overall Rating	Low/ Medium/ High

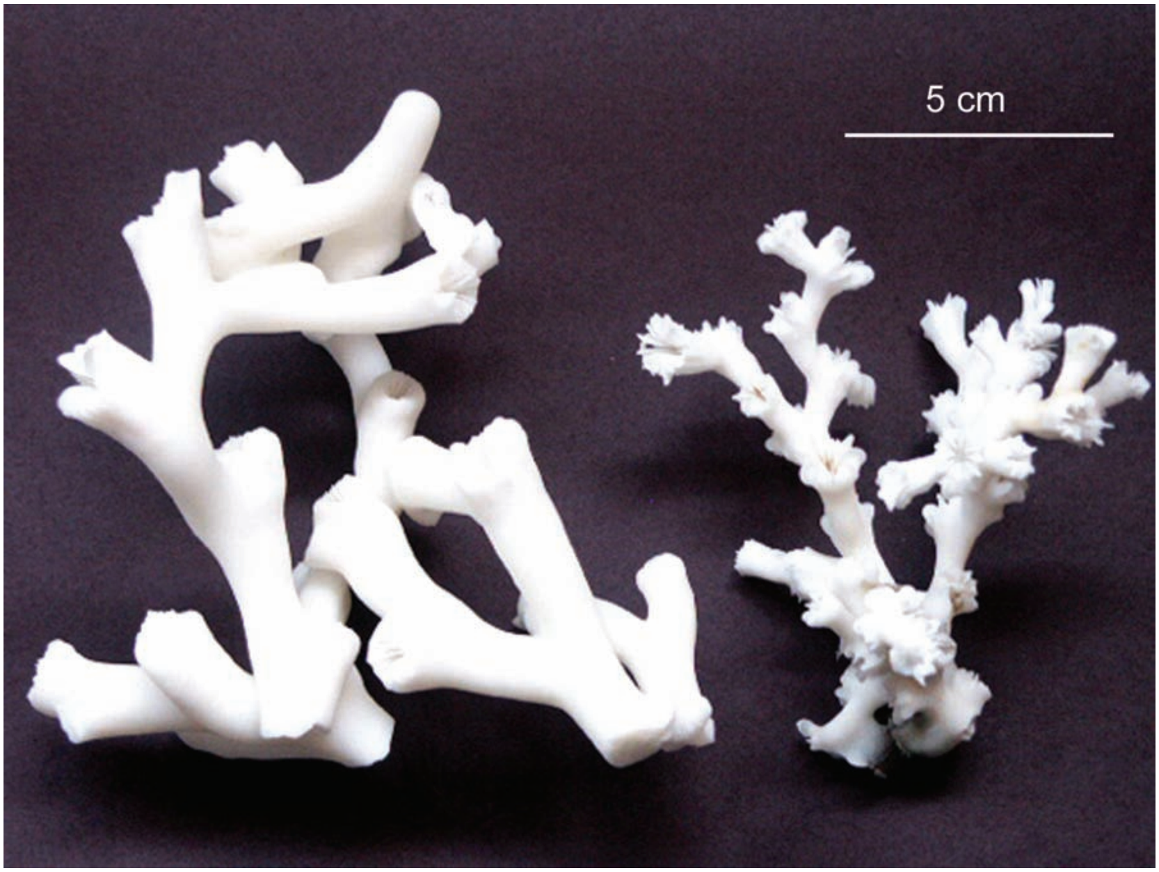

Figure 7.6. Samples of *Lophelia pertusa* colonies collected from the Gulf of Mexico showing (left morph) heavily calcified morphology (brachycephala) with large polyps from VK826, and (right morph) fragile morphology (gracilis) from GC354. Photo credit: S. Brooke OIMB.

could tolerate sediment loads of 54 mg L^{-1} for up to 2 weeks with approximately 90% survival, but increasing the sediment load to 103 mg L^{-1} caused almost 50% mortality over the same time period.

Other colonial species found in this region include *Madrepora oculata* (Linnaeus 1758), which forms large individual colonies on authigenic carbonate boulders in the northern Gulf of Mexico (Figure 7.7), but unlike *L. pertusa,* does not form monospecific coral stands and does not co-occur with *L. pertusa* thickets as habitat forming structure. M*adrepora carolina* has also been recorded from the northern Gulf of Mexico and the Florida Straits (Cairns 1979). In addition, *Solenosmilia variabilis* and *Enallopsammia profunda* are found on the carbonate slope habitats in the eastern Gulf of Mexico, but the extent of either species is unclear.

In addition to these azooxanthellate scleractinian corals, there are areas in the Gulf of Mexico where zooxanthellate coral reefs have been found at depths greater than 50m. These areas include the reefs of the East and West Flower Gardens Banks and the unique communities at McGrail Bank, which are dominated by *Stephanocoenia* sp. (Schmahl and Hickerson 2006). Zooxanthellate structure-forming scleractinians are also found on Pulley Ridge on the southwest Florida shelf, where zooxanthellate corals such as *Agaricia* sp., thrive at depths of 60-70m. Since these are not true deepwater corals, but rather shallow water species that have extended into deeper water, they will not be addressed in detail in this report.

b. *Black corals* (Class Anthozoa, Order Antipatharia)

At least 20 species of antipatharians have been documented for the Gulf of Mexico region (Appendix 1) with at least half of these identified from the Flower Gardens Banks area. Other samples have been collected and are awaiting identification or description (S. Brooke pers. obs.). Black corals are locally very common in some areas of the northern Gulf of Mexico and the Florida Straits. Some species grow into large bushy colonies (eg *Leiopathes*

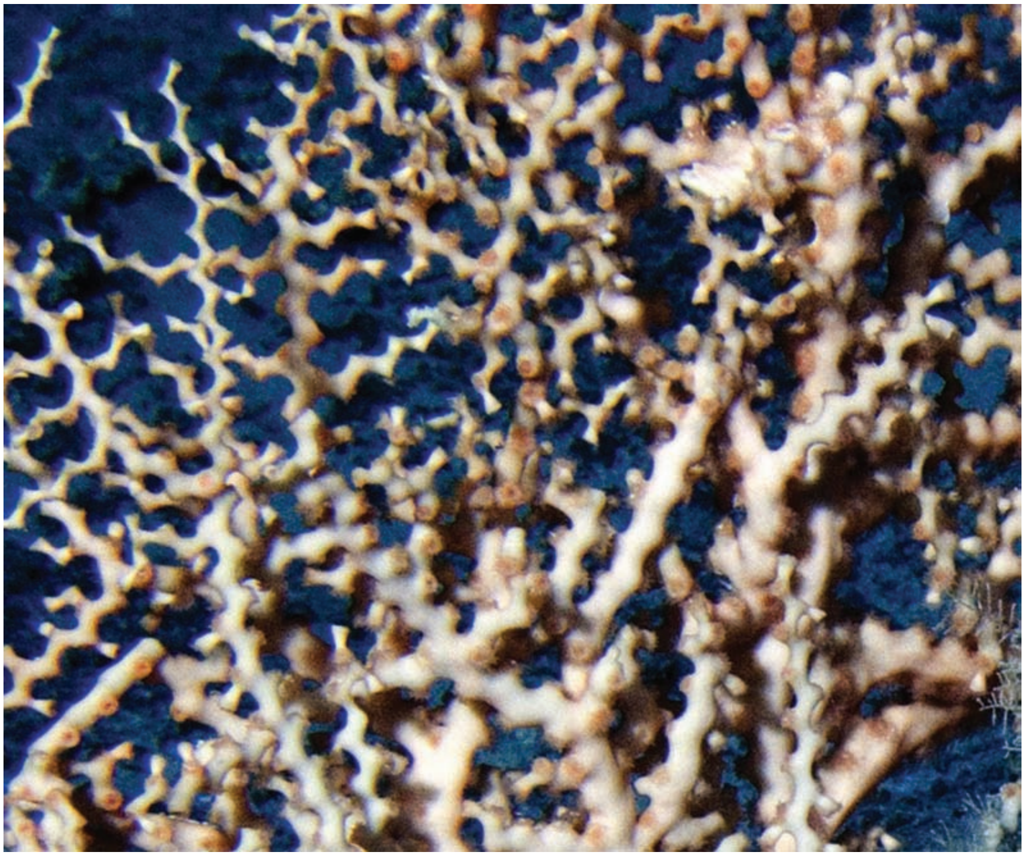

Figure 7.7. Large colony of *Madrepora oculata* showing distinctive zig-zag branch morphology. Photo credit: Brooke et al. and NOAA-OE

sp.*)* which may provide substrate and refuge for other organisms. Unlike some of the other taxa, there seems to limited geographical separation in the distribution of most of the species. Exceptions to this observation are the *Leiopathes* species, which were only documented for the northern Gulf of Mexico. Three colony colors (red, orange and white) have been collected and deposited at the National Museum of Natural History, but it is still unclear whether they are conspecific color morphs or distinct species (D. Opresko pers.comm.). The most thorough investigation on reproduction of black corals was conducted on *Antipathes fiordensis* from the southwestern New Zealand Fjords (Parker et al. 1997). Colonies were gonochoristic, and gametogenesis was rapid and synchronous, beginning in November and terminating in March. Colonies reached sexual maturity between the heights of 70 and 105 cm which corresponded to a minimum age for sexual maturity of about 31 yr. Such information is not available for the deep Gulf of Mexico species therefore it is unknown whether late reproductive maturity is a characteristic of this taxa.

c. *Gold corals* (Class Anthozoa, Order Zoanthidea)

Gold corals are not known in this region.

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

There are numerous species of octocorals in the deep waters of the Gulf of Mexico (many of which are still unidentified), the majority of which belong to the family Plexauridae; however Cairns and Bayer (2002) have identified several species of the habitat-forming primnoid *Callogorgia* spp. occurring throughout the Gulf of Mexico. At least one subspecies, *Callogorgia americana delta* is endemic. Most of these species contribute to multi-species coral habitats, but some occur as dense monotypic assemblages in localized areas in the northern Gulf of Mexico. These include the bamboo coral *Acanella arbuscula* (family Isididae) and *C. americana delta*, which is known to provide nursery habitat for oviparous cat sharks that deposit their egg cases on the branches (Etnoyer and Warrenchuck in press, S. Brooke pers. obs.), and is often seen with large fleshy ophiuroids (*Asteroschema* sp.) entangled in the colonies (Figure 7.8). A list of octocorals found in the Gulf of Mexico region can be found in Appendix 1. A comprehensive octocoral species inventory is currently being updated by Dr. S. Cairns of the National Museum of Natural History for publication in 2007. Gorgonians are an important component of the shelf edge reefs and banks of the northwestern Gulf of Mexico between 50 and 120m depth, and the FGBNMS research team is developing catalogs of octocorals, antipatharians and sponges found on these features (E. Hickerson pers.comm.). Despite being an important component of many deepwater hard-bottom communities, octocoral biology is not well understood. A study of reproduction in multiple species of common deepwater octocorals is currently underway (Simpson, pers.comm.). Information to date shows that there is variation in reproductive strategy within this order (Fitzsimmons–Sosa et al. 2004, Brooke unpublished data).

e. *True soft corals* (Class Anthozoa, Order Alcyonacea)

Several species of soft corals have been documented for this region (Appendix 1). A*nthomastus* (*Bathyalcyon) robustus delta* was often found in hardbottom habitats of the northern Gulf of Mexico at ~274m and at shallower depths (50-135m) *Chironepthya (=Siphonogorgia) caribaea* was encountered regularly in surveys of hardbottom areas in the NW GOM (E. Hickerson pers. comm.). None of the soft coral species contribute significantly to habitat structure since they neither form large colonies nor have solid skeletons. Very little is known about the biology of these taxa.

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

There are at least two species of pennatulaceans recorded for the Gulf of Mexico, and these were collected at greater depths (2683m) than the majority of the other cnidaria in the region (NMNH database). These taxa are often found on soft substrate and are the dominant benthic fauna in some areas (e.g. *Halipteris willemoisi* in Alaska); however there is insufficient information on distribution and abundance to determine whether this is the case for the pennatulaceans in the Gulf of Mexico.

g. *Stylasterids* (Class Hydrozoa, Order Anthoathecatae, family Stylasteridae)

Stylasterid hydrocorals are common components of the benthic communities of the bioherms and sinkholes of the Florida Straits, and the SW Florida shelf lithoherms, but have not been recorded in

Figure 7.8. *Callogorgia americana delta*, a gorgonian from the northern Gulf of Mexico, showing *Euryalid ophiuroids* entwined in the branches. Photo credit: OIMB for MMS.

the northern Gulf of Mexico basin. Stylasterids are usually absent from areas with high suspended-sediment, which may be detrimental to both juvenile and adult colonies (Ostarello 1973, Cairns 1992). They generally have slow growth rates, long life, and brooded larvae, and may be out-competed by more aggressive species in high nutrient waters, finding refuge in low nutrient and/or less competitive environments such as cryptic and deep-water habitats (Sanders 1979, Thayer 1989, Cairns 1992). A list of stylasterid species currently documented for the Gulf of Mexico, is presented in Appendix 7.1. Taxonomic descriptors follow revisions of the taxa by Cairns (1986). Dense communities of stylasterids have been observed on the bioherms of the central and eastern Pourtales Terrace, primarily along the tops and flanks of the structures (Reed et al. 2005b) and thick piles of dead and live stylasterid colonies were observed in some locations, but without coring the interior, it was not possible to ascertain how much contribution these stylasterid colonies made to the accumulation of the bioherms. Stylasterids are also one of the dominant sessile taxa of the southwest Florida Shelf *Lophelia* lithoherms (Reed 2004, Reed et al. 2006b)

V. SPATIAL DISTRIBUTION OF CORAL SPECIES AND HABITATS

The distribution of coral communities in the Gulf of Mexico region can be divided by geologic setting and depth. Dozens of reefs and banks are scattered across the shelf edge of the Gulf of Mexico, particularly in the northwestern region. Many of these features are formed by salt diaparism, which have pushed the sediments up into the photic zone. On the shallowest of these domes, zooxanthellate coral reefs and coral communities have developed, and are flanked by diverse communities of octocorals, antipatharians, and sponges. Authigenic carbonate deposits

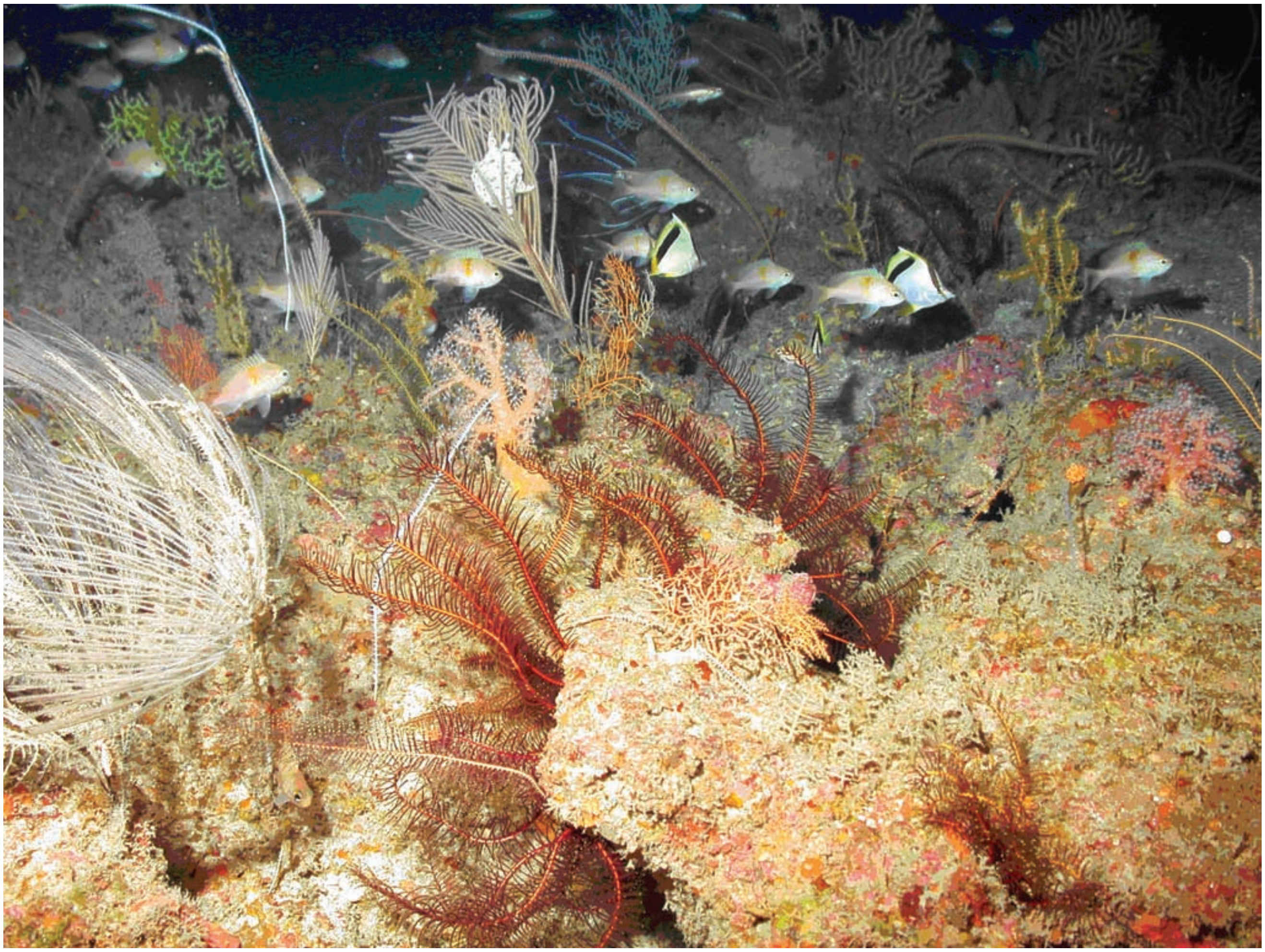

Figure 7.9. An example of deep coral habitat at the Flower Garden Banks National Marine Sanctuary, typical of the NW Gulf of Mexico habitats. Image includes octocorals, antipatharians, echinoderms, sponges, octocorals and deep water fishes. Photo credit FGNMS/NURC-UNCW.

along the deeper parts of the northern shelf and slope provide hard substrate for *L. pertusa* communities as well as other scleractinians octocorals and antipatharians (see Cairns et al. 1994). Zooxanthellate coral reefs are also found along the top of the west Florida shelf (<100m), and, at deeper depths, the west Florida slope and the terraces of the Florida Straits support extensive *L. pertusa* formations as well as stylasterine and sponge-dominated communities (Reed et al. 2005b).

Northern Gulf of Mexico

The benthos of the northwestern Gulf of Mexico is composed of terrigenous sediments, interspersed with dozens of reefs and banks, many of which are connected by corridors of hardbottom features. The East and West Flower Garden Banks, within the FGBNMS, support the northernmost zooxanthellate coral reefs in the U.S.A., with scleractinian coral cover of up to 70%, which is much higher than comparable coral reefs in the Caribbean basin (Precht et al. 2005; Rezak et al. 1985). These banks are just two of many reefs and banks that support rich communities of antipatharians, octocorals and sponges at depths between 50 and 150m (Figure 7.9). The FGBNMS has developed a database of information derived from more than 8300 digital images, taken during >160 ROV surveys in the northwestern GOM. In addition, approximately 200 antipatharian, octocoral and sponge samples were collected in order to produce regional catalogs for each taxon.

The deeper regions on the northern Gulf of Mexico slope cannot support zooxanthellate corals but are known to have fairly extensive areas of *L. pertusa* communities. These are located in an area known as Green Canyon off Louisiana and on the upper flanks and on Viosca Knoll, a deep-water salt dome off Alabama and Mississippi. More detailed distribution patterns are described below.

Viosca Knoll

The most well developed and well-documented *L. pertusa* communities in the Gulf of Mexico occur on the southwest flank of a mound in the southwest corner of Viosca Knoll lease block 826 (29° 09.5′ N 88° 01.0′ W, 430-520 m) on the upper DeSoto slope. Bottom sediments consist of authigenic carbonate and unconsolidated clay, silty clay, disarticulated shells, and shell hash. Authigenic carbonate formations are abundant at this site, especially on the crest and flanks of the mound, and occur in the form of large plates, slabs, and irregular shaped blocks, boulders, and rubble (Schroeder 2002). Representative ranges of near-bottom temperature, salinity, and dissolved oxygen values for the coral habitat obtained ~13 km east of the site), are 7.0-9.3° C, 34.9-35.1 psu, and 2.6-3.2 ml L^{-1}, respectively (Schroeder 2002).

Hard substrate on the crest and flanks of the mound support large and abundant colonies of *L. pertusa* (Schroeder 2002). These colonies have a bushy morphology composed of irregular, dendritic branches that are highly anastomosed and heavily calcified with large polyps. Individual colonies range in size from a few centimeters to over 1.5 m in diameter, while aggregations of closely associated colonies attain 1.5 to 2 m in height and width and 3 to 4m in length. Many of the aggregated colonies appear to be in the first phase of the "thicket" building stage described by Squires (1964). Colonies less than 25 to 50 cm in diameter were predominantly 100% live. Larger colonies and aggregated colonies often had dead branches (light to dark brown in color) at their base and center with live terminal branches, and some were 100% dead coral. This site is associated with a mature chemosynthethic community, consisting primarily of living tubeworm aggregations, but no known mussel beds or hydrates.

In 1955, the *M/V Oregon* collected approximately 136 kg of *L. pertusa* from a deep-water reef system, comprised of several sections up to 300 m long and 55 m deep (Moore and Bullis, 1960). The coordinates of the sampling site (29° 05.0'N, 88° 19.0′W, 421-512m) were revisited by the U.S. Navy submarine NR-1 in 2002 (Schroeder pers. obs.), but there were no *L. pertusa* reefs found at this location. The depth recorder tracing presented by Moore and Bullis (1960) is similar to the cross-sectional profile of a submarine canyon in lease block VK 862/906 (29° 06.4′N, 88° 22.9'W). This area is comprised of a topographic high located on the northern edge of an exposed carbonate rock complex that extends southward for over 2 km to the eastern rim of the canyon. Water depths range between 300 - 500 m. This lease block region has been explored using ROV (Sonsub Innovator), submersible (JSL) and submarine (NR-1) but the *L. pertusa* habitat

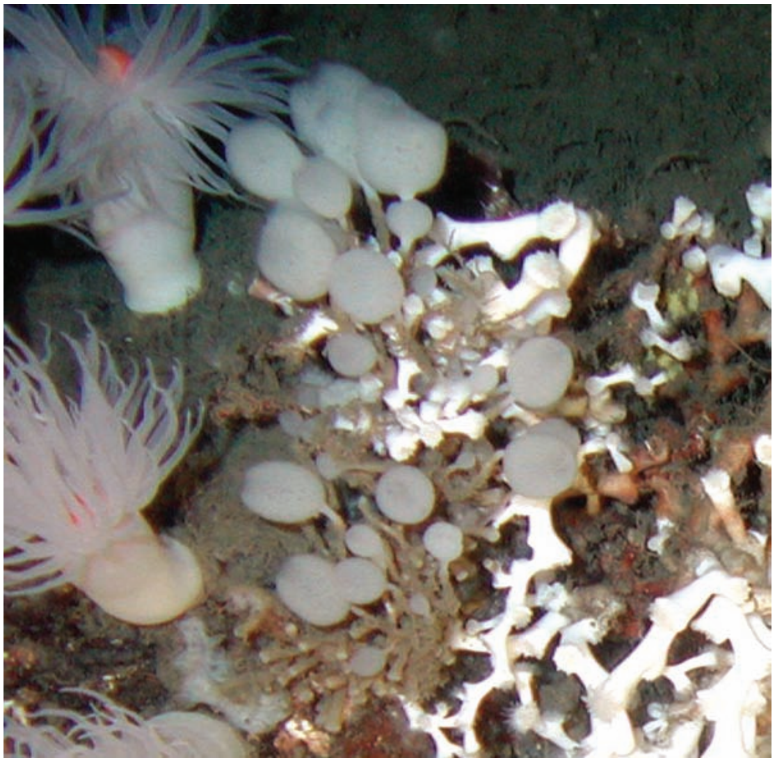

Figure 7.10. Image of unidentified white anemones and hexactinellid sponges found in high numbers at VK862 (Figure 7.3) Photo credit: OIMB for MMS.

described by Moore and Bullis has not been located. This reef may have been buried by a slumping event, or simply has not yet been found.

An unidentified species (or several species) of white anemone dominates the fauna in this region (Figure 7.10). They can be extremely abundant (up to 94 m^{-2}) and occur on flat substrate as well as carbonate outcroppings (Figure 7.11), and often co-occur with an unidentified species of hexactinellid sponge. The large carbonate boulders support diverse assemblages of corals including *L. pertusa* colonies, dense aggregations of bamboo corals (Isididae), *C. americana delta* (Primnoidae) and large black corals (Antipathidiae) (Continental Shelf Associates in review)

Mississippi Canyon

A low relief mound-like sea floor feature with abundant authigenic carbonate rock lies within Mississippi Canyon lease block 885 at a depth of 625 m (28˚03.78’N, 89^{o}42.62’W). It is an area of active seepage and includes bacterial mats, mussel beds, shells of dead clams, tubeworm aggregations and brine seepage. Interspersed among these areas of active seepage are carbonate outcrops with small *Lophelia pertusa* colonies and larger carbonate mounds with larger colonies of both *L. pertusa* and *Madrepora oculata.* There are also areas of high *C. americana delta* abundance, but overall coral species diversity at this site is low (Continental Shelf Associates in review)

Green Canyon

Thickets of aggregated *L. pertusa* colonies exist along a single ridge in an area of Green Canyon lease block 234 (27^{o} 44. 81 ’N, 91^{o} 13.13 ’W). The ridge is approximately 130 m in length and is comprised predominantly of dead *Lophelia pertusa* with live outer branches. Some of the thickets are large (several m^{3}) with occasional colonies of 100% live coral. On one side of this ridge is a large area with extremely abundant *Callogorgia americana delta* colonies. This is an area of active seepage, as evidenced by tubeworm aggregations observed close to the coral ridge.

Green Canyon lease block 184/185, commonly known as Bush Hill, is a low-relief knoll located in approximately 580 m of water. In addition to numerous aggregations of old tubeworms, both gas hydrates and mussel beds are present at this site. The central chemosynthetic communities are bordered on the northwest corner of the knoll by a series of large authigenic carbonate outcrops. Abundant large gorgonians (*C. americana delta* and other species) and colonies of *L. pertusa* are present on these outcrops and on an escarpment on the western side of the knoll.

The explored part of Green Canyon lease block 354 (between 27^{o} 35.9’N 91^{o} 49.6’W and 27^{o} 35.8’N, 91^{o} 49.4’W) is part of a slope that descends from 520 to 560 m. Abundant authigenic carbonate boulders on the upper portion of the slope support large *Lophelia pertusa* thickets of 5 to 10 m in diameter. Scattered vestimentiferans and some large tubeworm aggregations are interspersed with these boulders. Down-slope of this area, there are occasional large pockmarks with slumping sediments and authigenic carbonate outcrops supporting smaller *L. pertusa* and *Madrepora*

oculata colonies (Continental Shelf Associates in review)
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West Florida Shelf and Slope

There are numerous hardbottom habitats along the west Florida shelf from Panama City to the Dry Tortugas (Schroeder et al. 1989). One of the most well-known is the Florida Middle Grounds in the eastern Gulf of Mexico. The bank formations consist of two parallel ridges separated by a valley and 23 species of stony coral and 170 species of fish have been recorded from this area (Nipper et al. 2006). Other high relief reefs off the western Florida panhandle are associated with the rim of the De Soto Canyon. These reefs are popular fishing grounds for snapper and grouper and include Madison Swanson, Mud Banks and Twin Ridges to the northeast and lower relief structure such as The Edges and Steamboat Lumps. Southern shelf edge reef areas include Howel Hook, Hambone Ridge, Northwest Peaks, Christmas Ridge and Pulley Ridge (Koenig et al. 2000b). Pulley Ridge is a series of drowned, barrier islands on the southwest Florida Shelf which form a ridge about 5 km across with less than 10 m relief. The shallowest parts of the ridge are about 60 m deep and the southern portion supports zooxanthellate scleractinian corals, making it the deepest hermatypic reef in the U.S.A. Atlantic. The corals *Agaricia* sp. and *Leptoceris cucullata* are most abundant, forming plates up to 50 cm in diameter. Less common species include *Montastraea cavernosa, Madracis formosa, Madracis decactis, Porites divaricata,* and *Oculina tellena* (Halley et al. 2005). Deepwater ahermatypic coral mounds occur along the 500 m isobath of the west Florida Slope for approximately 20 km between 26° 20'N, 84° 45'W to 26° 30N, 84° 50'W, with individual coral mounds between 5 and 15 m tall. The lithoherms consist of rugged black phosphorite-coated limestone boulders and outcrops capped with 0.5-1.0 m tall thickets of *L. pertusa* (Reed et al. 2006). The *R/V Aleutian Bounty* collected the first recorded samples of *Lophelia pertusa* and *Madrepora oculata* from this area (26°30.0′ N, 84°50.0′ W, 640 m) in a trawl net in 1983. In 1984 the *R/V Cape Hatteras* also collected samples of corals from the mounds using rock dredges (Newton et al. 1987). Colonies of *M. oculata* were also reported at much lower abundance, together with a solitary coral *Bathypsammia*

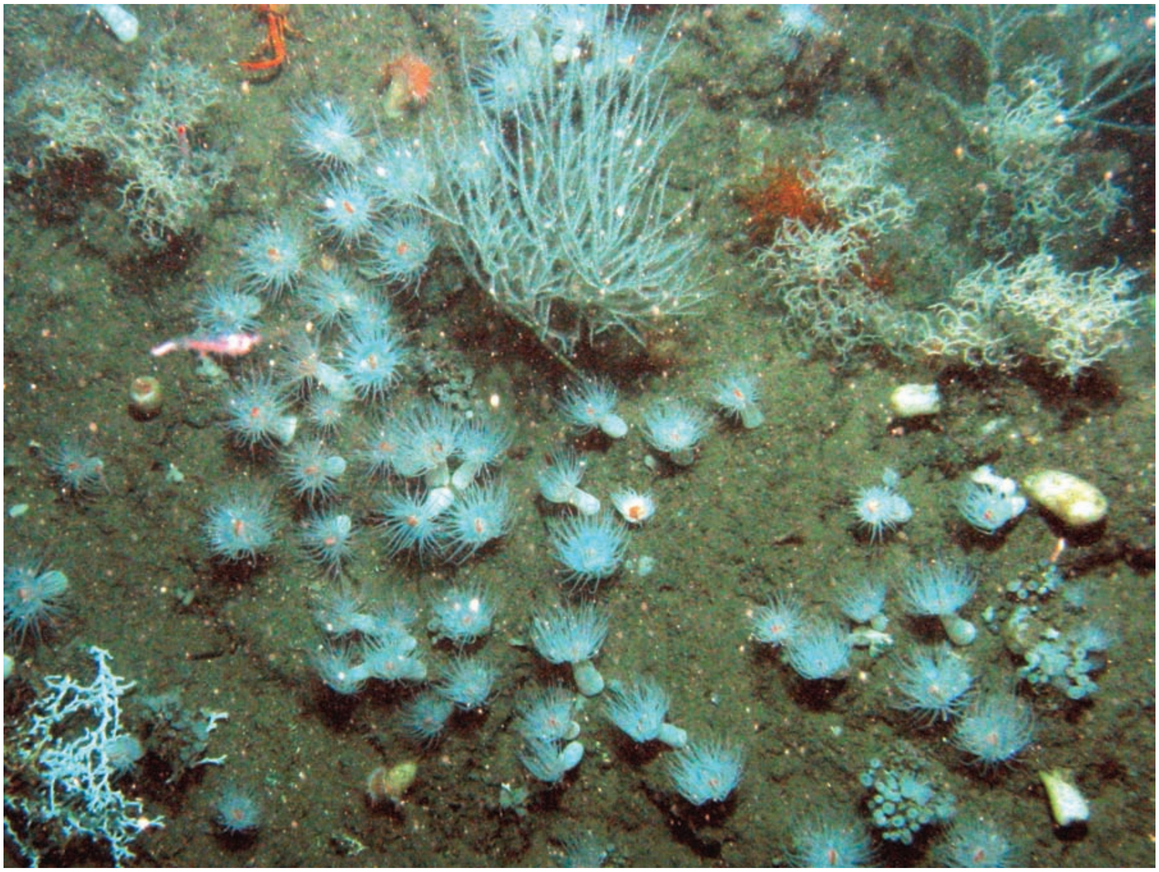

Figure 7.11. This image shows the different kinds of anemones that represent the dominant benthic fauna at VK862 (See figure 7.3). Photos credit: OIMB for MMS.

sp. All corals recovered in the 1984 collections were dead; however in 2003, the SONSUB ROV was used to ground-truth three of the slope features: a 36-m tall escarpment and two of the many lithoherms (Reed et al. 2004, Reed and Wright 2004, Reed et al. 2005b). The dominant fauna on the 36 m escarpment consisted of an antipatharian species (approx 30 cm high), an isidid bamboo coral (30-40 cm high) and numerous other octocorals, plus several species of sponge (*Heterotella* sp., *Phakellia* sp., Corallistidae). The benthic communities of the lithoherms differed from those of the escarpment in that thickets of live and dead *L. pertusa* were found on some of the slope terraces and the top ridges. Coral cover was estimated at <5% to >50% in some areas, but was only 1-20% alive (Reed et al. 2006). Dominant sessile macrofauna included stony corals, octocorals, stylasterid hydrocorals, black corals (*Antipathes* sp. and *Cirrhipathes* sp.) and sponges from the families Hexactinellidae and Demospongiae (Reed et al. 2004).

Florida Straits

Between 1999 and 2005, the *Clelia* and *Johnson-Sea-Link* (JSL) submersibles were used to survey several high relief sites on the Pourtales Terrace, including the Jordan and Marathon sinkholes and five of the high relief lithoherms on the central portion of the terrace (Reed et al. 2004, 2005b). The peaks of some of the mounds were covered with thick layers of stylasterid corals along with dense and diverse communities of sponges and octocorals (Reed et al., 2005b). Cnidarians included 3 species of antipatharian black coral, 5 stylasterid hydrocorals, 11 octocorals, and 1 scleractinian. Stylasterid and antipatharian corals were also common on the flat pavement adjacent to the base of the mounds. High densities of sponges, stylasterid corals and octocorals were observed, particularly on the bioherm plateaus and terraces. Sponges and stylasterids also dominated slopes of the bioherms but at much lower densities than the plateaus, whereas the octocorals were generally found at higher densities on the slopes (Reed et al. 2005b). Certain species occurred only on the Pourtales sinkholes and were not found on the bioherms; these included two identified species of antipatharians (*Antipathes rigida* and *A. tanacetum*), three species of octocorals (*Paramuricea placomus, Plumarella pourtalesii* and *Trachimuricea hirta)* and the scleractinian *Solenosmilia variabilis.*

Along the eastern edge of the Miami Terrace at a depth of 365 m is a 90 m tall steep rock ridge capped with *L. pertusa,* stylasterid corals, bamboo coral, black coral, and various sponges and octocorals (Reed et al. 2004, 2006b). The benthic communities of the Pourtales Terrace bioherms however, differ from those of the lithoherms along the northeastern Straits of Florida (Messing et al. 1990) primarily due to an absence of *L. pertusa* and a dominance of stylasterid corals and stalked crinoids (Reed et al. 2004, 2006b).

Shipwrecks

There are 7,000 reported shipwrecks in the Gulf of Mexico. While most pose no threat to the environment many were carrying cargoes of fuel and other materials and these may lose their structural integrity over time. The contribution of these wrecks to habitat development is currently unknown; they may serve as temporary substrate for coral colonization and structure for fish and invertebrate populations, until their deterioration releases fuel and other pollutants. They also may serve as an initial focus for development of an established habitat.

The ‘Deep Wrecks Project’ funded by the Minerals Management Service and NOAA, with researchers from C&C Technologies, Inc., used an industrial ROV (Sonsub Inc) to archaeologically and ecologically assess seven World War II era vessels sunk by U-boats in the Gulf of Mexico. Since these sites ranged in depths from 87 m to almost 2,000 m, they offered biologists a unique opportunity to study the artificial reef effect in differing ecological niches. Three of the vessels, the *Virginia, Halo* and *Gulfpenn,* are located south of the Mississippi delta in water depths of 87 m, 143 m and 554 m, respectively and supported several deep sea coral families. Scleractinians were found on all three wrecks, with four of the five species occurring on the *Virginia* (*Madracis myriaster, Oculina varicosa, Paracyathus pulchellus* and *Pourtalosmilia conferta),* two species on the *Halo* (*M. myriaster* and *P. conferta)* and two species on the *Gulfpenn* (*P. conferta* and *L. pertusa).* Gorgonians were collected from and/or observed on the two shallowest wrecks. The *Halo* had a well-developed gorgonian fauna, including four species that were collected from the wreck (*Placogorgia rudis, Thesea* sp. cf. *T. grandiflora, Thesea* sp. cf. *T. rubra* and *Thesea* sp.*)* and one unidentified species recorded on video. A single, large colony of *Muricea pendula* was found on the *Virginia,* together with two species of antipatharians (*Antipathes furcata* and *Stichopathes* sp. cf. *S. pourtalesi),* which occurred only on the *Virginia.* All species, except *Oculina varicosa,* have previously been reported from the Gulf of Mexico.

VI. SPECIES ASSOCIATIONS WITH DEEP CORAL COMMUNITIES

Information on deepwater coral-associated fauna in the Gulf of Mexico region comes from historic trawl and dredge samples (e.g., Agassiz 1869, Moore and Bullis 1960, Newton et al. 1987), and also from recent ROV and submersible operations.

Northern Gulf of Mexico

Antipatharian, octocoral, and sponge communities associated with hardbottom areas in the Northwestern Gulf of Mexico contain abundant populations of both commercial and non-commercial fish species, including *Lutjanus campechanus* (red snapper), *Rhomboplites aurorubens* (vermillion snapper), *Pronotogrammus martinicensis* (roughtongue bass), *Anthias tenuis* (threadnose bass), and several species of grouper. Initial observations from the FGBNMS research suggest correlations between the benthic community structure and composition and the mobile fauna (E. Hickerson pers. comm.). Rezak et al. (1985) provide a list of fish associated with reefs and banks in the northwestern Gulf of Mexico.

Unlike many other *Lophelia* reefs, the northern Gulf of Mexico *L. pertusa* communities have not been shown to support commercially important fisheries species. Large schools of *Hyperoglyphe perciformis* (barrelfish) have been observed at Viosca Knoll lease block 862 (S. Brooke pers. obs.). These are caught along with *Polyprion americanus* (wreckfish) along the U.S. eastern coast, and they are marketed along with *Beryx splendens* and *B. decadactylus* (alfonsinos). Although there is currently no commercial fishery for barrelfish in the northern Gulf of Mexico, there is potential for development of a future fishery for this species. Information on *Lophelia*-associated fish species has been documented (Sulak et al, in press) during a series of cruises in the northern Gulf of Mexico.

Commercially important deepwater invertebrates that exist in the northern Gulf include *Pleoticus robustus* (royal red shrimp) and *Chaceon fenneri* (golden crab) (Snyder 2000), although there is currently no fishery for golden crab species in the northern Gulf of Mexico. Royal red shrimp occur over specific substrata in different areas: terrigenous silt and silty clay off the Mississippi Delta and calcareous mud off the Dry Tortugas, with peak abundance at 250-500 m depth. Golden crabs occur over a similar depth range, but prefer hard bottom and outcroppings such as the Florida escarpment (Lindberg and Lockhart 1993). The Moore and Bullis site (located in 1955) discussed previously, was reported to be ‘over half a mile long and up to 180 ft thick’. Records indicate a single trawl drag recovered “several hundred pounds of fish, shrimp, starfish, urchins and other animals”. This site has not been found since that time, but recent research in the nearby Viosca Knoll area (Continental Shelf Associates in review) has shown that *L. pertusa* habitat supports a similar coral-associated community as that reported by Moore and Bullis. In addition, *L. pertusa* colonies provide habitat for the surrounding slope community, but probably do not directly provide food to other organisms, with the exception of the gastropod *Coralliophila* sp. Some species are found at higher densities close to *L. pertusa* or have been found only in tight association with coral habitat. These species include the squat lobster *Eumunida picta*, comatulid crinoids, unidentified sponge species and, in dead coral skeleton only, sabellid polychates (Continental Shelf Associates in review).

West Florida Shelf and Slope

NMFS landing statistics show higher landings of deepwater reef species than the rest of the Gulf. For the grouper family (Serranidae), the highest catches were for *Epinephelus flavolimbatus* (yellowedge grouper), which are associated with low-relief hard bottom habitats up to 250 m deep. Other serranid species such as *E. niveatus* (snowy grouper), *E. drummondhayi* (speckled hind) and *E. nigritus* (warsaw grouper) were also found on deepwater hard bottom structure, but landings of these species were consistently much lower than for *E. flavolimbatus*.. Hard-bottom species such as *Etelis oculatus* (queen snapper) and *Hyperoglyphe perciformis* (barrelfish) were minor contributors to the commercial fishery. These data encompass the entire west coast of Florida, including the popular shallower fishing grounds on the Florida shelf and shelf edge. These habitats serve as spawning aggregation sites for commercially valuable species such as *Mycteroperca microlepis* and *M. phenax* (gag and scamp) as well as habitat for other commercial grouper and snapper species. In June 2000 the Madison Swanson/Steamboat Lumps marine reserves were implemented (with a 4 year sunset clause that was extended in 2004), and all fishing was banned except trolling for highly migratory and coastal pelagic species between May 1st and October 31st. This was done in an effort to protect grouper spawning stocks and has proved a successful policy, despite illegal fishing, which is still a problem on these offshore areas (Koenig pers. comm.). There are no landings data currently available specifically for the deepwater coral lithoherms, and since many are deeper than 250 m, the shallower nearshore regions are probably contributing the majority of the catch. There is also a small fishery for *Chaceon fenneri* (golden crab), which reached a peak of 640 metric tons in 1995, but by 2004 had declined to 25 metric tons. During a study of golden crab distribution and behavior (Lindberg and Lockhart 1993), the greatest density was found among gorgonians and in crevices on hard bottom at depths of 350-550 m. The coordinates of the survey correspond to the lithoherm region on the west Florida slope, but fishing data do not indicate precisely where landed crabs were caught.

Dominant sessile macrofauna on the west Florida slope lithoherms included stony corals, gorgonians, stylasterids, antipatharians and sponges (Reed and Wright, 2004). These coral habitats provide complex structure for abundant and diverse communities of associated fish, crustaceans (including the golden crab, *C. fenneri),* mollusks, echinoderms, polychaete and sipunculan worms, anemones, terebratulid brachiopods, bryozoans and other sessile and motile macrofauna, some of which are probably undescribed species (Newton et al. 1987, Reed 2004). Preliminary studies discovered new species of octocorals and sponges from some of these sites (Reed et al. 2004). Messing (unpublished) found an unstalked crinoid assemblage (159 m) not known to occur elsewhere in Florida but characteristic of deeper Cuban and Bahamian waters (>300 m).

Florida Straits

A total of 31 fish taxa (of which 24 were identified to species level) have been identified from the sinkhole and bioherm sites of the Pourtales Terrace (Reed et al. 2004). Common species on the high-relief bioherms included *Antigonia capros* (deepbody boarfish), *Lopholatilus microps* (blueline tilefish), *Epinephelus niveatus* (snowy grouper), and *Holanthias martinensis* (roughtongue bass). Some species, such as the snowy grouper, blackbelly rosefish (*Helicolenus dactylopterus)* and mora (*Laemonema melanurum),* were common at both the sinkhole and bioherm sites. This region is shallower in places than the SW Florida lithoherms or the Northern Gulf of Mexico regions, and supports commercially valuable species such as *E. drummondhayi* (speckled hind), *E. flavolimbatus* (yellowedge grouper), *E. nigritus* (warsaw grouper), *Pagrus pagrus* (red porgy), *Seriola* sp. (amberjack) and *Pareques iwamotoi* (blackbar drum), as well as deeper species such as *E. niveatus* (snowy grouper), *H. dactylopterus* (blackbelly rosefish), *Lopholatilus* sp. (tilefish) and *Urophycis* sp. (phycid hakes). The fish densities appeared insufficient to support a viable commercial or recreational fishery, since only a few individuals of the larger grouper species were present at any one site (Reed 2004). A swordfish was also observed on top of Pourtales Terrace from the NR-1 submersible (C. Paull, pers. obs.), and the JSL submersible was attacked twice during dives on the Terrace and sinkholes (Reed pers.comm.)

There is extremely limited information on coral associated fauna from the Pourtales Terrace. Trawl collections from the Terrace (Agassiz 1869) contained an abundant and unique benthic assemblage of invertebrates rarely found elsewhere in the Straits of Florida, e.g., the hydroid *Cladocarpus sigma,* and the unstalked crinoids *Comatonia cristata* and *Coccometra hageni* (Bogle 1975, Meyer et al. 1978). The most recent published information on the communities of the Florida straits deepwater habitats are by Reed (2004) and Reed et al. (2005b). These manuscripts document the coral communities and their associated fauna collected during submersible and ROV cruises, but represent a

Table 7.2 Potential and Current Fishing Gear Impacts on Deep Sea Corals

Gear Type	Potential Severity of Impact	Potential Extent of Impact from Fishing Gear	Current Geographic Extent of Use in Region	Overlap of use with coral habitat	Overall Rating of Gear Impact
Bottom Trawl	High	High	Low	Uncertain	Low-Medium
Mid-water Trawl	Low	Low	Medium	Uncertain	Uncertain
Dredge	High	Low	N/A	N/A	N/A
Bottom-set Longline	Medium	Low	Low	Uncertain	Low
Bottom-set Gillnet	Medium	Medium	N/A	N/A	N/A
Longline traps or pots	High	Medium	Low	Uncertain	Uncertain
Single pots	Low	Medium	Low	Uncertain	Uncertain
Hook and line	Low	Low	Low to medium*	Yes	Low
	*may increase as recreational trophy fishing increases				

small percentage of the highly biodiverse habitat assemblages.

VII. STRESSORS ON DEEP CORAL COMMUNITIES

The most significant global threats to deep corals are destructive fishing practices, particularly trawling, that compromises the habitat infrastructure, and often occurs repeatedly in the same area, thus preventing and habitat recovery; however, trawling is not a significant problem in the deep Gulf of Mexico (Table 7.2). Another potential stressor is the expanding exploration and exploitation of fossil fuel reserves in the deep Gulf of Mexico.

Fishery Effects

Bottom trawling

Trawling for the various varieties of shrimp (*Farfantepenaeus duorarum, Penaeus setiferus, P. aztecus)* represents the most lucrative fishery in the Gulf of Mexico; however these shrimp are fished over soft sediments at less than 50 m depth therefore it is unlikely that these shrimp fisheries have damaged deep coral habitats. Trawling for *Pleoticus robustus* (royal red shrimp) occurs in water depths of 400-500 m off Florida Texas and Alabama. Gear used for royal red shrimp is similar to trawling gear for shallow species, but to work in deepwater the trawl doors and lines must be much heavier. Since royal red shrimp inhabits soft substrate (silt and calcareous mud) this fishery probably does not target deepwater coral habitat, but damage could occur if the shrimp habitat is adjacent to coral communities or if equipment is erroneously deployed in coral habitat. There are currently no other deepwater trawl fisheries operating in this region.

Scallop dredges

There is a dredge fishery in the Gulf of Mexico for *Argopecten gibbus* (calico scallops); it is infrequent but when scallops are present in high numbers, vessels come from as far as the mid-Atlantic coast to participate in the fishery (Arnold 2006; NMFS 1982), and there is some potential for impacts to deep coral since these scallops can be found in water depths of 10-400 m. The present condition of stock in the South Atlantic region is unknown because of large fluctuations in abundance and the last commercial landings of calico scallops from the Gulf coast of Florida was in 2000 (http://research.myfwc.com)

Deep Gill Nets

Gillnets are allowed for the spanish and king mackerel fishery, and for non-FMP commercial and recreational fisheries. There is no deep water managed species that is fished using gillnets.

Bottom Long-lines

Fishing for ‘highly migratory species’ such as tuna and swordfish (*Xiphias gladius*) is one of the most lucrative in the Gulf of Mexico, primarily using surface long-lines. These are not deep enough to interfere with coral habitat, but damage could occur however if the lines break and drag across the coral habitat. Many sharks are fished with bottom longlines, particularly on the shelf-slope break and these have potential to damage fragile benthos.

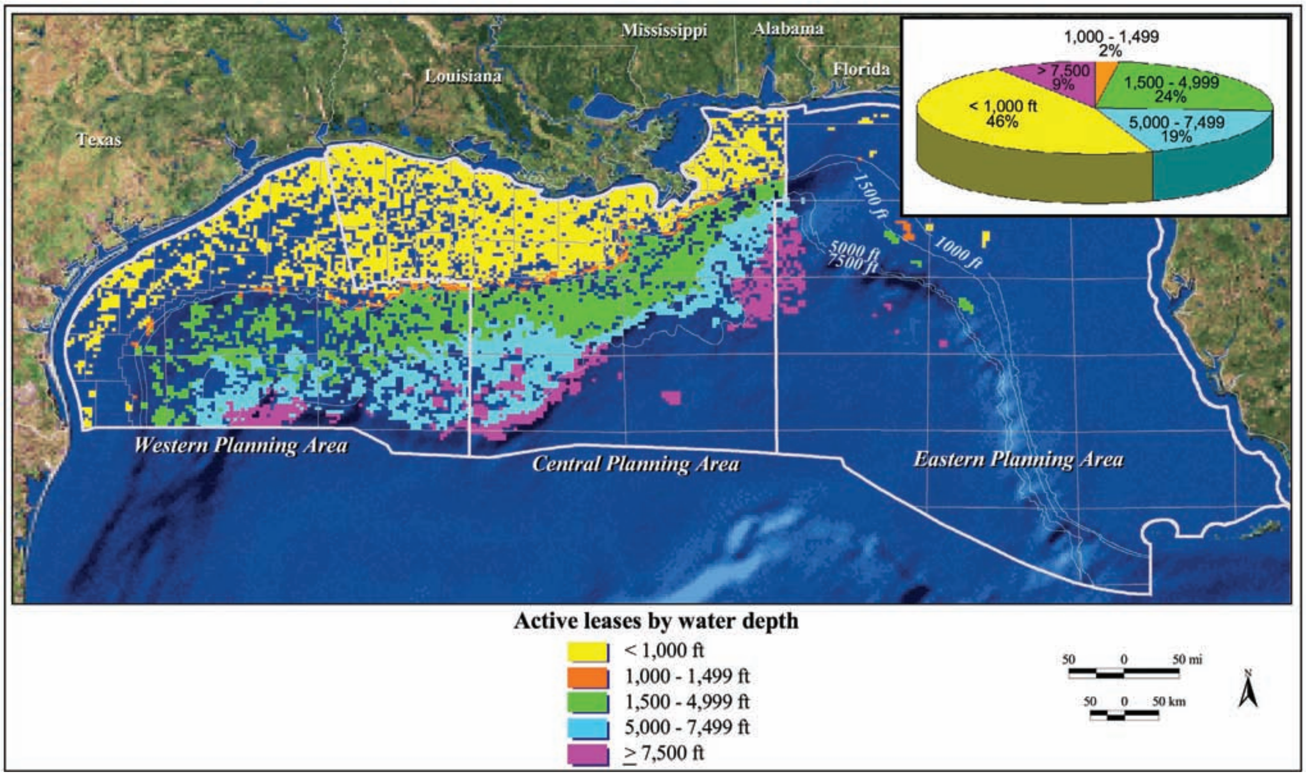

Figure 7.12. Active oil and gas leases in the Gulf of Mexico. Map credit: MMS

Demersal or reef fishes caught in deepwater include *Epinephelus flavolimbatus* (yellowedge grouper), *E. niveatus* (snowy grouper), *E. nigritus* (warsaw grouper), *Etelis oculatus* (queen snapper) and *Lutjanus vivanus* (silk snapper), plus *Caulolatilus microps* (blueline tilefish) and *Caulolatilus chrysops* (goldface tilefish), which are generally found on soft sediment benthos rather than reefs or hardbottom. These species are primarily harvested using bottom long-lines, with some traps or hook and lines used. Bottom long-lines are much shorter than pelagic lines, but can be up to 30 km long (Snyder 2000). These lines can damage fragile coral habitat, especially in areas of high current where lines may be dragged or heavily weighted. Numerous lost long-lines have been observed on the seafloor during submersible dives in the deepwater Naples sinkhole (200m) on the west Florida shelf, and deepwater sinkholes and bioherms of the Pourtales Terrrace (Reed pers. comm.)

Traps and Pots

Golden crab gear consists of rectangular wire mesh traps that are attached in series along a weighted mainline and are recovered by hauling the mainline aboard the boat. Golden crabs have been observed on hard bottom habitat in the region of the Florida lithoherms (Lindberg and Lockhart 1993) and are fished on the Pourtales Terrace (Reed pers.comm.). If the traps were placed close to the coral, recovery of the trap could result in dragging it over the coral and potentially damaging the coral.

Harvest of precious corals

There is currently no commercial harvesting of precious corals in this region; however there are areas that support abundant populations of antipatharians, which are harvested in other areas (e.g. Hawaii) for making ornaments and jewelry.

Effects of Other Human Activities

Oil and Gas Exploration and Extraction

The Gulf of Mexico supports the largest offshore oil and gas extraction fields in the nation. Currently, there are approximately 4,000 producing platforms, of which about 1,962 are major platforms and approximately 152 companies are active in the Gulf of Mexico (http://www.gomr.mms.gov) (Figure 7.12). The deep waters of the Gulf of Mexico (>300 m) where deep coral resources may occur have been an area of increasing exploration and development over the past decade. Deep-water oil production has risen 386% since 1996 and accounts for 62% of the total oil production in the Gulf of Mexico. By the end of 1999, approximately 1,200 wells had been drilled in water depths greater than 1000 ft (305 m). In 2003, an estimated 350 million barrels were produced from deepwater rigs. Deep water gas production has increased by 407% since 1996, reaching an estimated 1.42 trillion cubic feet (Tcf) in 2003, and has surpassed shallow water production (U.S. Department of the Interior 2000, 2004).

Direct physical impact to the substrate has been observed at Viosca Knoll 826 (Schroeder 2002). At 496 m on the western flank, a furrow was observed in the soft sediment that extended both up- and down-slope. The furrow alternated between a completely disrupted surface over a 1-1.5 m swath, and a clean, narrow cut into the soft sediment. There was no extensive destruction of carbonate structures; however, numerous colonies and aggregations of *L. pertusa*, attached to buried carbonate material, were severely damaged. It was surmised that this disruption occurred when a wire anchor cable, deployed in conjunction with oil and gas drilling operations in this region, struck the bottom one or more times. Apart from the physical impact, the other primary environmental threat from oil and gas exploration/extraction is accidental leakage of drilling fluids or oil into the water column. Drilling in deep water requires special drilling fluids that can operate at low temperatures. Synthetic-based drill fluids (SBF) have been used in the Gulf of Mexico since 1992 and are well suited to deepwater use (Boland et al. 2004). These fluids do not contain the toxic polycyclic aromatic hydrocarbons that are found in non-synthetic drill fluids that are refined from crude oil. Use of SBF in the Gulf of Mexico is limited to rapidly-biodegradable esters and internal olefins; however, the accidental release of drilling fluid still presents potential environmental hazards through release of large quantities of sediment and anaerobic decomposition of the organic SBF material at the sediment surface. Drilling fluid may also be mixed at the time of release with oil containing toxic components.

The number of chemical spills in the Gulf of Mexico has steadily increased. In 1998 27% of all incidents in U.S. waters took place in the Gulf of Mexico (Boehm et al. 2001). In 2003, an SBF spill occurred when a drilling pipe fractured in two places at an oil lease block site in Mississippi Canyon (MC778), located at 28.19°N, 88.49°W at a depth of 1840 m. An environmental impact assessment conducted by MMS (Boland et al. 2004) concluded that the SBF dispersed into the water, settled to the seafloor and biodegraded. The SBF would cause a temporary decrease in dissolved oxygen at the sediment water interface therefore the less motile animals within the nearby benthic community (mud bottom with low biodiversity) could have smothered under a layer of SBF or from anoxic conditions resulting from biodegradation, but that the community would recover once the SBF biodegrades. In this case, there were no strong currents, the sediment settled close to the accident and fortuitously did not impact a sensitive habitat, but this may not always be the case. If oil rather than SBF was released, the fluid would be more toxic, although it may be carried vertically away from the benthos since it is less dense than water. Interestingly, the report mentions that the closest chemosynthetic communities were at VK826, and were not close enough to be impacted by the spill, but made no mention of potential impact to the extensive *Lophelia* communities in the same lease block. Deposition of organic and potentially toxic sediment could cause extensive coral mortality from direct toxicity, smothering by sediments, and reduction in oxygen content. These reefs are slow growing and their recruitment rates are unknown. As oil and gas exploration increases, it is vital that corals are included in the MMS environmental impact assessments and are given the same status as chemosynthetic communities.

Deployment of Gas Pipelines and Communication Cables

The deployment of gas pipelines and cables can impact deep coral communities through sediment re-suspension during the burial process (especially in shallower areas), and can cause habitat destruction during pipeline deployment as a direct result of the pipes and also from anchor-cable sweep and anchor drag. While there has been a decline in the production of natural gas from the shallower existing lease areas in the Gulf of Mexico, the Minerals Management Service (MMS) began offering incentives in 2001 to encourage drilling in deeper waters. Koenig et al. (2000a) reported on the potential impact of gas pipelines proposed for deployment in two marine protected areas in the Gulf of Mexico and evaluated the potential destructive effects of the process. MMS regulations do not require burial and anchoring of pipelines laid at depths greater than 61 m. Other habitat impacts may be associated with deployment of pipelines. Each anchor measures approximately 5 x 6 m and weighs at least 13 tons and together with the cables cover a swath approximately one nautical mile wide As they are positioning the anchors, the cables act like trawls or dredges as they sweep across the bottom. The combined effects of the anchor-cable sweep, anchor drag and sea state determines the extent of the habitat damage.

The extent of the damage caused by pipeline construction is evaluated by MMS using clearly defined habitat descriptions. The MMS considers live-bottom to be "seagrass communities or those areas which contain biological assemblages consisting of sessile invertebrates, such as sea fans, sea whips, hydroids, anemones, ascidians, sponges, bryozoans, or corals living upon and attached to naturally-occurring hard or rocky formations with rough, broken, or smooth topography; or areas whose lithotope favors the accumulation of turtles, fishes, and other fauna" (Koenig et al. 2000a). Since the MMS does not require oil and gas exploration companies to survey areas at a depth greater than 100 m important habitats including coral areas may be exposed to potential damage or destruction. These habitats include: essential fish habitat (EFH) for *Lopholatilus chamaeleonticeps* (tilefish), *Caulolatilus microps* (blueline tilefish), *Epinephelus nigritus* (warsaw grouper), *E. niveatus* (snowy grouper), *E. drummondhayi* (speckled hind), and *E. flavolimbatus* (yellowedge grouper) (Parker and Mays 1998). The southwest Florida shelf has been found to have extensive live-bottom coverage (65%) at depths of 120 to 160 m (Phillips et al. 1990), however the number, extent and location of deep coral habitats in the Gulf of Mexico are unknown.

Gulf Fiber Corporation installed a deep water fiber optic cable system called Fiber Web in 1999. This has been updated over the past 3 years and stretches from Texas to Florida in a loop that runs from onshore to the 200 m isobath, along the shelf edge and back onshore again. These cables are not thick and heavy like pipelines, but there is potential for environmental impact when they are laid or replaced. In 2003, Florida Department of Environmental Protection initiated a policy that directs underwater communications cables to be sited through gaps in reef tracts. This protects reefs under Florida state jurisdiction, but there is no such legislation for deep water corals in federal waters.

Mineral mining

The Gulf of Mexico has extremely large stores of methane hydrate, which is a solid crystal lattice comprised of water and methane. Research over the past two decades has shown that methane hydrate exists as void-filling in shallow sediments, and as massive mounds, often associated with chemosynthetic biota. At the moment, the extraction of these hydrates is in the experimental phase, but there is an interagency road map in place for the research and development of methane hydrate as a potential future energy source (U.S. Department of Energy, 2006). In the deep Gulf of Mexico, corals are often found close to chemosynthetic activity, since the hard substrate is of authigenic origin. Methane hydrate extraction is not an immediate threat but could have future consequences for deep water chemosynthetic and coral communities.

Sedimentation

There are natural events that could temporarily increase sedimentation, such as benthic storms or deepwater gyre activity, but unless they are unusually severe or protracted, the sessile benthic fauna will have evolved to deal with such events. Anthropogenic sediment input could be caused by fossil fuel exploration or extraction, not only by resuspension of local sediments but also from drilling muds. Release of petroleum products or other extraction related contaminants is also a potential threat to benthic organisms. Currently the MMS Notice to Lessees issued in 2000 states that "*If you propose activities that could disturb seafloor areas in water depths 400 meters (1,312 feet) or greater, maintain the following separation distances from features or areas that could support high-density chemosynthetic communities: 1) At least 1,500 feet from each proposed muds and cuttings discharge location and 2) At least 250 feet from the location of all other proposed seafloor disturbances (including those caused by anchors, anchor chains, wire ropes, seafloor template installation, and pipeline construction).*" This notice does not mention avoidance of coral communities.

VIII. MANAGEMENT OF FISHERY RESOURCES AND HABITATS

Fisheries in the area covered by this report are managed undr fishery management plans (FMPs) by two regional councils, the Gulf of Mexico Fishery Management Council (GMFMC) and the South Atlantic Fishery Management Council (SAFMC). The Gulf of Mexico Fishery Management Council is responsible for fisheries in federal waters off the coasts from Texas to the west coast of Florida (www.gulfcouncil.org) and the South Atlantic Fishery Management Council is responsible for fisheries in federal waters off the coasts of North Carolina, South Carolina, Georgia and east Florida to Key West (http://www.safmc.net).

The GMFMC produced a Coral and Coral Reefs FMP with the SAFMC in 1982. The species currently covered under this FMP include "species belonging to the Orders Stolonifera, Telestacea, Alcyonacea (soft corals), Gorgonacea (horny corals, sea fans, sea whips), and Pennatulacea (sea pens) in the Subclass Octocorallia; Orders Scleractinia (stony corals) and Antipatharia (black corals) in the Subclass Zoantharia; and the Orders Milleporina (fire corals, stinging corals) and Stylasterina in the Class Hydrozoa". These classes include many deep coral species and therefore apply to deep corals as well as their shallow water counterparts. In March 2005, the GMFMC proposed amending their description of coral EFH to "the total distribution of coral species and life stages throughout the Gulf of Mexico including: coral reefs in the North and South Tortugas Ecological Reserves, East and West Flower Garden Banks, McGrail Bank, and the southern portion of Pulley Ridge; hard bottom areas scattered along the pinnacles, reefs, and banks from Texas to Mississippi along the shelf edge and at the Florida Middle Grounds; the southwest tip of the Florida reef tract, and the predominant patchy hard bottom offshore of Florida from approximately Crystal River south to the Keys".

On January 23, 2006, the National Marine Fisheries Service established Habitat Areas of Particular Concern proposed by the Gulf of Mexico Fisheries Management Council. Fishing restrictions prohibit bottom longlining, bottom trawling, buoy gear, dredge, pot, or trap and bottom anchoring by fishing vessels at West and East Flower Garden Banks, Stetson Bank, McGrail Bank, and an area of Pulley's Ridge. Additional restrictions on fishing were already in place at the Tortugas Ecological Reserves and Madison-Swanson and Steamboat Lumps Marine Reserves. Other Gulf of Mexico HAPC's that do not carry any regulations are the remainder of Pulley Ridge, the Florida Middle Grounds, and the following banks: 29 Fathom, MacNeil, Rezak, Sidner, Rankin, Bright, Geyer, Bouma, Sonnier, Alderdice, and Jakkula Banks. No regulations are currently in place for these HAPC areas, but they will be considered during individual fishery plan review and development.

These EFH HAPC were targeted toward the zooxanthellate coral communities, some of which occur at deeper depths than usual, but include areas that are biologically significant due to their antipatharian, octocoral, and sponge communities. The HAPCs do not include habitats where the structure-forming azooxanthellate scleractinians such as *L. pertusa* are found. Currently there are no proposed protected areas for these communities which are only found at depths >300 m in the Gulf of Mexico. The SAFMC however, has proposed the designation of HAPC status to several areas within their jurisdiction, including the deep-water coral habitats on the Pourtales Terrace. For further information and updates, refer to the SAFMC website.

Flower Gardens Banks National Marine Sanctuary

In the 1970's researchers and recreational divers initiated a 20 year effort to protect the reefs of the Flower Gardens Banks, culminating in the designation of the FGBNMS in 1992, which comprised the Eastern and Western Flower Gardens Banks. In October, 1996, Congress expanded the Sanctuary by adding Stetson Bank, which is a small salt dome located about 110 km south of Galveston, Texas. The total area of the sanctuary encompasses 144 km^2, which includes 1.6 km^2 of reef crest at approximately 18-25m, with zooxanthellate corals occuring to at least 52 m. Fishing within the Sanctuary is regulated through fishery management plans developed in cooperation with the Gulf of Mexico Fishery Management Council. In addition to the original protected areas, HAPC designations were granted in 2006 for selected deeper banks noted above. These sites were proposed to the GMFMC by the FGBNMS based on the deepwater communities of octocorals, gorgonians, and antipatharians.

IX. REGIONAL PRIORITIES TO UNDERSTAND AND CONSERVE DEEP CORAL COMMUNITIES

Deepwater corals exist throughout the Gulf of Mexico however their distribution has not been comprehensively surveyed or mapped and there are a very limited number of publications on coral habitat or associated fauna (Agassiz 1869, Moore and Bullis 1960, Bogle 1975, Meyer et al. 1978, Newton et al. 1987, Lindberg and Lockhart 1993, Schroeder 2002, Reed 2004, Reed et al. 2004, Reed and Wright 2004, Reed et al. 2006). Most of the information regarding deep coral habitat is either anecdotal, proprietary or in preparation from current projects. NOAA's Office of Ocean Exploration has supported, and continues to support, exploration of deepwater coral habitat throughout the U.S. EEZ. The Flower Garden Banks NMS approaches deepwater investigations on a regional basis, and will continue to look for opportunities to further the science in the northwestern Gulf of Mexico. The Minerals Management Service has recently funded a 3-year research project to characterize coral habitat, associated fauna and coral biology in the northern Gulf of Mexico (Continental Shelf Associates in review), but there is still a need for additional research in many areas, some of which are listed below.

Map coral habitat

- Deep coral habitat may be far more extensive than current knowledge indicates. In shallower areas on the shelf (<200m), there are extensive areas of hardbottom, produced primarily through salt tectonics, which provide substrate for coral community development. The deeper slope and basins are dominated by soft sediment habitats, but sessile organisms (such as corals and sponges) colonize exposed rocky outcrops of authigenic carbonate. The geology of the Gulf of Mexico has been well studied, primarily because of fossil fuel interests, so there is some indication of the distribution of different substrate types. This information has been used (and should continue to be used) as a starting point for 'ground-truthing' explorations. Areas of special ecological importance should be defined so that protection can be proactive rather than reactionary.

Priority mapping areas

- The high numbers of hard bottom lithoherms on the Southwest Florida slope, together with the diverse habitats discovered in the few explorations undertaken in this region indicate tremendous potential for unexplored coral and fish habitat.
- The Pourtales Terrace region has a different community composition from the other two regions and the limited exploration to date has shown community difference between sinkholes and lithoherms, which raise interesting ecological questions. Also, this region supports several potential fisheries species, but little is known of their abundance or ecological association with the corals.
- In the Northwestern Gulf of Mexico, the Flower Gardens NMS has identified a priority for mapping geological features between banks that may connect them, biologically and ecologically. Limited groundtruthing has revealed deepwater assemblages including octocorals, antipatharians and sponges associated with these features.

Identify and describe areas of EFH

- Since the GMFMC manages deep coral species under its Coral and Coral Reefs FMP the protection measures available under EFH regulations should provide a framework for the application of the Magnuson-Stevens Fishery Conservation and Management Act (National Marine Fisheries Service, 1996). Most areas currently identified by the Council primarily reflect the distribution of shallow-water hermatypic corals. There is a need to identify the locations of deep coral communities, particularly in those areas that may be subject to future trawling (e.g., for royal red shrimp) or other anthropogenic impacts (e.g., pipeline construction or other oil and gas-related activities).

Increase research of important but understudied taxonomic groups

- Most deepwater coral research to date has focused on the structure-forming scleractinia; however, members of the antipatharia, gorgonacea and stylasterids also provide habitat structure and may be an important part of an ecosystem. Taxonomic and some distributional data are available from museum inventories and institutional databases; however, with the increase in deepwater exploration in recent years, the databases may not be current. There are also many images available from underwater still and video cameras, but in many cases these cannot provide definitive identification. Additionally almost nothing is known about the ecology of these important groups.

- The porifera are also in urgent need of study, but the identification of the many taxa that contribute to habitat complexity is an extensive undertaking.

With the increasing level of oil and gas exploration in the northern Gulf of Mexico, surveying for fossil fuel exploration and environmental impact assessments by the energy industry could potentially provide video footage and anecdotal information on coral distribution. These data are not always available; however with increased cooperation between industry and science, such information could become a valuable resource. The SERPENT (Scientific and Environmental ROV Partnership using Existing Industrial Technology) program is an example of successful cooperation between multiple industry and scientific partners around the globe, including the Gulf of Mexico (http://www.serpentproject.com).

Cooperation with the MMS could potentially change environmental impact and protection policies to include areas of diverse hard bottom communities in the deep Gulf of Mexico and elsewhere. Policies could be implemented to protect coral communities and EFH from the direct effects of exploration and extraction of oil and gas, including deployment of cables and pipelines. Additionally, buffer zones could be created so that fossil fuel operations would be excluded within a ‘reasonable’ distance (to be defined) from coral habitat, to minimize the effect of construction and accidents.

X. CONCLUSION

The extent of deepwater coral habitat in the Gulf of Mexico is unknown at present, but in general, where there is hard substrate there is some degree of benthic community cover, and this is frequently dominated by cnidarians. Coral communities are found under various environmental conditions, from the hard substrate scattered throughout the shelf and slope of the northern Gulf of Mexico, to the carbonate shelf and slope of the west Florida shelf and the Florida Straits. Corals require hard substrate for settlement and sufficient water flow to deliver food and oxygen, and remove waste products, but not so much that feeding mechanisms or skeletal growth is impacted. They require particulate food since the true deepwater corals are azooxanthellate and must obtain their nutrition from zooplankton (possibly augmented by marine detritus and dissolved organic material), therefore factors that drive zooplankton dynamics may also influence coral distribution. Sediment load may affect coral communities, particularly those groups with very small polyps such as the stylasterids. The removal of fine particles from coral polyps is facilitated by mucous shedding and requires energetic expenditure. Finally (but not exhaustively) currents must deliver larvae to the appropriate habitats. There are large areas of bare, apparently suitable substrate in the northern Gulf of Mexico that have not been colonized (S. Brooke pers. obs.). Recruitment limitation is one possible explanation, but our understanding of the ecology of these deepwater coral habitats is still rudimentary.

The role of *L. pertusa* in structuring the surrounding slope community appears to be through the provision of habitat rather than direct provision of nutrition by *L. pertusa,* with the possible exception of the gastropod *Coralliophila* sp. *L. pertusa* creates habitat for a number of associated species, many of which show significantly higher densities in proximity to coral or have been found only in tight association with *L. pertusa* in the Gulf of Mexico. These include *Eumunida picta* (a species of squat lobster commonly seen on deepwater coral habitats in the southern U.S.A.), comatulid crinoids, sabellid polychaetes, and sponges (Continental Shelf Associates, in review). The coral associated species found in the Gulf of Mexico appear similar to those encountered on the *L. pertusa* reefs off the east coast of Florida, although there has not yet been a rigorous comparison. The coral communities in the Florida Straits are different from those of the northern Gulf of Mexico and the west Florida shelf and are dominated by stylasterine and sponge communities. Several species of Pleurotomarid gastropods are found on the shallower carbonate slopes and sinkholes on the Pourtales Terrace, but are not found in the Gulf of Mexico basin.

Of all the deepwater coral communities addressed in this report, the only ones that show evidence of human impact are the shallower fishing grounds on the west Florida shelf. The grouper spawning aggregations on these mounds have been severely overfished (Koenig et al. 2000b), which prompted the GMFMC to grant protected status to Madison Swanson and Steamboat Lumps. The reefs and banks on the continental shelf edge of the northern Gulf of Mexico are protected through various regulatory agencies (NOAA's National Marine Fisheries Service and Minerals Management Service). Regulations do not overlap, which may allow environmental impacts to occur, such as dynamiting coral reefs for salvage purposes, and methods of closing these gaps should be investigated and proposed. Whatever these alternatives are, should also be considered for off-shelf deepwater communities. The golden crab fishery could potentially damage coral on the west Florida slope, especially if the fishery expands in the future, but there are currently no major commercial trawl fisheries in the Gulf of Mexico to seriously impact deepwater coral habitat. The oil and gas industry is expanding rapidly in deepwater and will probably continue to do so far into the future. The laying of pipelines and cables, boat anchors and spills could all potentially cause extensive damage to coral habitat unless activity is restricted by regulations and enforced appropriately. The most well studied and most extensive *L. pertusa* habitat in the Gulf of Mexico is within the the Viosca Knoll lease block 826, and the adjacent lease block 862 also supports a highly biodiverse area with abundant fish populations (Continental Shelf Associates in review). Although there is no apparent immediate threat, these areas are unique as far as current investigation can determine and as such are worthy of protection from potential anthropogenic impact. Another region of interest is the lithoherm habitat on the west Florida shelf edge. The extent and health of this system is unknown and is a high priority for further research. There are many areas of the deep Gulf of Mexico that have not been explored and further investigation may discover more coral habitats. At present there are fewer immediate threats to Gulf of Mexico ecosystems than in certain other areas, but a proactive approach to habitat protection may be more effective than one which reacts to user groups that are already invested in the exploitation of a resource.

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Appendix 7.1 Species list of deep coral species found in the Gulf of Mexico. Outlined/highlighted text indicates major structure forming species. Depth ranges are global depth ranges extracted from the literature. National Musuem of Natural History (NMNH), Texas A&M University (TAMU)

Taxon	Species	Distribution	Depth (m)*	Reference
Phylum Cnidaria				
Class Anthozoa				
Subclass Hexacorallia				
Order Scleractinia				
Family Caryophyllidae	*Anomocora fecunda* Pourtales 1871	SW Florida, N, NE GOM	73-779	Cairns 1978, 1987
	Asterosmilia prolifera Pourtales 1871	N. GOM	32-311	Cairns 1978
	Caryophyllia ambrosia Alcock 1898	SW Florida, N, NE GOM	183-2360	Cairns 1978
	Caryophyllia berteriana Duchassaing 1850	SW Florida, N.GOM	100-850	Cairns 1978, 1987
	Caryophyllia cornuformis Pourtales 1870	SW Florida	137-931	Cairns 1978
	Caryophyllia parvula Cairns 1979	N GOM	68-136	Cairns 1979
	Coenosmilia arbuscula Pourtales 1871	SW Florida	109-807	Cairns 1978
	Dasmosmilia variegata Pourtales 1871	SW Florida	185-600	Cairns 1978
	Dasmosmilia lymani Pourtales 1871	N. GOM	33-366	Cairns 1978
	Deltocyathus italicus Michelotti 1838	SW Florida, N.GOM	403-2634	Cairns 1978, 1987
	Deltocyathus calcar Pourtales 1874	SW Florida, N.GOM	101-675	Cairns 1978
	Deltocyathus eccentricus Cairns 1979	SW Florida, N.GOM	183-910	Cairns 1978
	Desmophyllum dianthus Esper 1794	NE SE GOM	900-1210	NMNH
	***Lophelia pertusa* (Linnaeus, 1758)**	**SW Florida, N. GOM, Wrecks**	**60-2170**	**Cairns 1978**
	Oxysmillia rotundifolia Milne Edwards and Haime 1849	N. GOM	46-640	Cairns 1978
	Paracyathus pulchellus Philippi 1842	SW Florida, N.GOM, Wrecks	25-838	Cairns 1978, TAMU
	Pepnocyathus stimpsonii Pourtales 1871	SW Florida	110-293	Cairns 1978
	***Pourtalosmilia conferta* Cairns, 1978**	**Wrecks**	**87-554**	**Schroeder pers. comm.**
	***Solenosmilia variabilis* Duncan, 1873**	**Florida Straits**	**220-3383**	**Cairns 1978, Reed et al. 2005b**
	Stephanocyathus diadema Moseley 1876	N. GOM	795-2133	Cairns 1978
	Stephanocyathus paliferus Cairns 1977	SW Florida	229-1158	Cairns 1978

Taxon	Species	Distribution	Depth (m)	Reference
	Stephanocyathus coronatus Pourtales 1867	N. GOM	543-1280	Cairns 1978
	Thalamophyllia riisei Duchassaing and Michelotti 1860	N. GOM	18-1317	Cairns 1979, 1987
	Theocyathus laevigatus Pourtales 1871	SW Florida	183-576	Cairns 1978
	Trochocyathus flos Pourtales 1878	N. GOM	22-560	Cairns 1978
	Trochocyathus rawsonii Pourtales 1874	SW Florida	131-622	Cairns 1978
Family Dendrophylliidae	*Balanophyllia palifera* Pourtales 1878	N. GOM	53-708	Cairns 1978, 1987
	Balanophyllia floridana	NE GOM	92m	Wicksten pers. com.
	Bathypsammia tintinnabulum Pourtales 1868	SW Florida	210-1079	Cairns 1978
	Bathypsammia? sp. Marenzeller, 1907	SW Florida	418-640	Reed et al. 2005b
	Dendrophyllia cornucopia Pourtales 1871	SW Florida	132-960	Cairns 1978
	Dendrophyllia alternata Pourtales 1880	N. GOM	276-1200	Cairns 1978
	***Enallopsammia profunda* Pourtales 1867**	**SW Florida**	**146-1748**	**Cairns 1978**
	Rhizopsammia manuelensis Chevalier 1966	N. GOM	55-366	Cairns 1978
Family Fungiacyathidae	*Fungiacyathus crispus* Pourtales 1871	SW Florida, N.GOM	183-1010	Cairns 1978
Family Flabellidae	*Flabellum moseleyi Pourtales 1880*	*SW Florida, N. GOM*	*216-1097*	*Cairns 1978*
	Flabellum fragile Cairns 1977	SW Florida	80-366	Cairns 1978
	Javania cailleti Duchassaing and Michelotti 1864	SW Florida, N. GOM	86-2165	Cairns 1978
	Rhizotrochus fragilis Pourtales 1868	SW Florida	90-796	Cairns 1978
Family Guyniidae	*Guynia annulata* Duncan 1872	SW Florida, N. GOM	3-653	Cairns 1978
	Schizocyathus fissilis Pourtales 1874	SW Florida, N. GOM	88-640	Cairns 1978
	Stenocyathus vermformis Pourtales 1868	SW Florida	128-1229	Cairns 1978
Family Oculinidae	***Madrepora oculata* Pourtales 1758**	**N. GOM**	**80-1500**	**Cairns 1978**
	***Madrepora carolina* Pourtales 1871**	**SW Florida, N.GOM**	**53-1003**	**Cairns 1978**
	***Oculina varicosa* Lesueur, 1821**	**Wrecks**	**87**	**Schroeder pers. com.**
Family Pocilloporidae	*Madracis brueggemanni* Ridley	N GOM	55-127	NMNH
	Madracis myriaster Milne Edwards and Haime 1849	SW Florida, N.GOM, Wrecks	37-875	Cairns 1978
	Madracis formosa Wells 1973	SW Florida	46-104	NMNH

Taxon	Species	Distribution	Depth (m)	Reference
	Madracis pharensis	SW Florida	90	Wicksten pers. com.
Order Antipatharia				
	Acanthopathes thyoides	N. GOM	124	FGBNMS/Opresko
	Antipathes atlantica	N. GOM	77	FGBNMS/Opresko
	Antipathes sp. cf. *gracilis*	N. GOM	70	FGBNMS/Opresko
	Antipatharia, unid.	Florida Straits, N. GOM	283-767	Reed et al. 2005b
	Antipatharia, unid.	Florida Straits, SW Florida	328-515	Reed et al. 2005b
	Antipathes columnaris Duchassaing 1870	SW Florida	73-567	Cairns 1993
	Antipathes furcata Gray, 1857	Wrecks, N.GOM	87-106	FGBNMS/Opresko
	Antipathes rigida Pourtales, 1880	Florida Straits, S, N GOM	64-640	Cairns 1993, Reed et al. 2005b
	Antipathes pedata Gray 1857	SW Florida, N. GOM	60-308	Cairns 1993
	Antipathes tanacetum Pourtales 1880	Florida Straits, N. GOM	46-915	Cairns 1993
	Antipathes salix Pourtales 1880	SW Florida, N. GOM	107-263	Cairns 1993
	Aphanipathes abietina Pourtales 1874	SW Florida, N. GOM	31-310	Cairns 1993
	Aphanipathes pedata	N. GOM	131	FGBNMS/Opresko
	Bathypathes patula Brook 1889	SW Florida	100-5000	Cairns 1993
	Bathypathes alternata Brook, 1889	SW Florida	466-716	Reed et al. 2005b
	Elatopathes abietina	N. GOM	106	FGBNMS/Opresko
	***Leiopathes glaberrima* Esper., 1786**	**N. GOM**	**176-549**	**Cairns 1993**
	Phanopathes expansa	N. GOM	121	FGBNMS/Opresko
	Plumapathes pennacea	N. GOM	61	FGBNMS/Opresko
	Stichopathes sp. cf. *S. pourtalesi* Brook, 1889	Wrecks	87	Schroeder pers. com.
	Stichopathes lutkeni	N. GOM	64	FGBNMS/Opresko
	Tanacetipathes barbadensis	N. GOM	89	FGBNMS/Opresko
	Tanacetipathes tanacetum	N. GOM	107	FGBNMS/Opresko
Subclass Octocorallia				
Order Alcyonacea				
Family Alcyoniidae	*Anthomastus (Bathyalcyon) robustus delta* Bayer 1993	N GOM	274	NMNH
	Anthomastus sp.	Florida Straits		NMNH

Taxon	Species	Distribution	Depth (m)	Reference
Family Clavulariidae	*Telesto flavula* Deichmann 1936	N GOM		
	Telesto fruticulosa Dana	N GOM		
Family Nidaliidae	*Nidalia occidentalis* Gray 1835	N GOM	76-214	NMNH
	Siphonogorgia agassizii Deichmann 1936	N GOM	58-190	NMNH
	Chironepthya (Siphonogorgia) caribaea Deichmann 1936	NW GOM	75-135	NMNH/FGBNMS
Family Plexauridae	*Bebryce cinerea*	N GOM	107	FGBNMS/Williams
	Bebryce sp. cf. *cimeria*	N GOM	91	FGBNMS/Etnoyer
	Bebryce parastellata Deichmann 1936	N GOM	46-586	NMNH
	Caliacis nutans Duchassaing & Michelotti, 1864	SW Florida, N GOM	101-238	NMNH
	Echinomuricea atlantica Johnson, 1862	SW Florida	101-183	NMNH
	Hypnogorgia pendula Duchassaing & Michelotti, 1864	N GOM	60-183	NMNH
	Muricea pendula Verrill, 1864	Wrecks, N GOM	53-87	Schroeder pers. com., FGBNMS/ Cairns
	Muriceides sp. cf. *furta*	N. GOM	91	FGBNMS? Etnoyer
	Muriceides sp.	Florida Straits	191	Reed et al. 2005b
	Paramuricea multispina Deichmann, 1936	Florida Straits	176	NMNH
	Paramuricea placomus Linnaeus, 1924	Florida Straits	462-470	Reed et al. 2005b
	Paramuricea multispina Deichmann, 1936	Florida Straits	189-715	Reed et al. 2005b
	Placogorgia tenuis Verrill, 1883	Florida Straits, N. GOM	86-557	NMNH, Reed et al. 2005b, Etnoyer
	Placogorgia mirabilis Deichmann, 1936	Florida Straits, N. GOM	172-212	Reed et al. 2005b
	Placogorgia sp. *(red unidentified)*			
	Placogorgia rudis	Florida Straits, Wrecks	143-238	NMNH, Schroeder pers. com.
	Plumarella pourtalesi Verrill, 1883	Florida Straits	171-753	Reed et al. 2005b
	Scleractis guadaloupensis Duchassaing & Michelotti, 1860	N. GOM	58-190	
	Swiftia casta Verrill, 1883	Florida Straits	53-942	NMNH, Reed et al. 2005b

Taxon	Species	Distribution	Depth (m)	Reference
	Swiftia new sp.?	Florida Straits	497	Reed et al. 2005b
	Thesea sp. cf. *T. grandiflora* Deichmann, 1936	SW Florida, N GOM, Wrecks	143	NMNH, Schroeder pers. com.
	Thesea sp. cf. *T. rubra* Deichmann, 1936	N GOM, Wrecks	61-143	NMNH, Schroeder pers. com.
	Thesea sp.	Wrecks	143	Schroeder pers. com.
	Trachymuricea hirta Pourtales, 1867	Florida Straits	462	Reed et al. 2005b
	Thesea parviflora Deichmann, 1936	Florida Straits	183	Reed et al. 2005b
	Villogorgia nr. nigrescens Duchassaing & Michelotti, 1860	Florida Straits	215	Reed et al. 2005b
Order Gorgonacea				
Family Anthothelidae	*Diodogorgia nodulifera* Hargit in Rogers and Hargitt 1901	N. GOM	86	FGBNMS/Etnoyer
Family Chrysogorgiidae	*Chrysogorgia elegans*	SW Florida, N. GOM	162-732	NMNH
	Chrysogorgia spiculosa	Florida Straits, N. GOM	1256-2360	NMNH
Family Ellisellidae	*Ellisella atlantica* (Toeplitz)	N GOM	56-100	NMNH
	Ellisella barbadensis Duchassaing & Michelotti	Florida straits, NW, N GOM	64-390	NMNH
	Ellisella funiculina Duchassaing & Michelotti	NE GOM	55-92	NMNH
	Ellisella elongata Pallas	NE GOM	55-91	NMNH
	Nicella deichmani	N. GOM	107	FGBNMS/Cairns
	Nicella guadalupensis Duchassaing & Michelotti 1846	N GOM	68-159	NMNH
	Nicella goreaiu	N. GOM	86	FGBNMS/Etnoyer
	Riisea paniculata Duchassaing & Michelotti 1860	N GOM	188	NMNH
Family Gorgoniidae	*Leptogorgia stheno* Bayer	N GOM	69	NMNH
Family Isididae	***Acanella arbuscula***	**SW Florida, NW GOM**	**940m**	**NMNH**
	Acanella sp.	GOM	183-1216 m	Wicksten pers. com.
	***Keratoisis flexibilis* Pourtales 1868**	**N GOM, SW Florida, Florida Straits**	**378-816**	**NMNH**

Taxon	Species	Distribution	Depth (m)	Reference
Family Keroeididae	*Thelogorgia stellata* Bayer 1992	N. GOM	89	FGBNMS/Cairns
Family Primnoidae	***Callogorgia americana delta* Cairns and Bayer, 2002**	**N GOM**	**366-570**	**Cairns and Bayer 2002**
	Callogorgia americana americana Cairns and Bayer, 2002	Florida Straits	183-732	Cairns and Bayer 2002
	Callogorgia gracilis Milne Edwards and Haime, 1857	N. GOM	110	FGBNMS/Cairns
Order Pennatulacea				
	Umbellula guntheri Kolliker, 1880	N GOM	2683	NMNH
	Umbellula lindahlii Kolliker, 1874	N GOM	2683	NMNH
	Funiculina quadrangularis Pallas	N GOM	768	NMNH
Class Hydrozoa				
Order Anthoathecatae				
Family Stylasteridae	Stylasteridae, unid. sp.	Florida Straits	173-742	Reed et al. 2005b
	Stylaster erubescens Pourtales, 1868	Florida Straits	175-186	Reed et al. 2005b
	Stylaster miniatus Pourtales, 1868	Florida Straits	175-220	Reed et al. 2005b, NMNH
	Stylaster filogranus Pourtales, 1871	Florida Straits	175-366	Reed et al. 2005b, NMNH
	Stylaster unid. sp.1	Florida Straits	557	Reed et al. 2005b
	Stylaster laevigatus Cairns, 1986	Florida Straits	366	NMNH
	Stylaster aurantiacus Cairns, 1986	SW Florida	159-166	NMNH
	Stylaster gemmascens	Florida Straits	183	NMNH
	Distichopora foliacea Pourtales, 1868	Florida Straits	175	Reed et al. 2005b
	Crypthelia glossopoma Cairns, 1986	Florida Straits	205-210	NMNH
	Pliobothrus echinatus Cairns, 1986	Florida Straits	175	NMNH, Reed et al. 2005b
	** Note: Depth ranges are not just GOM samples, but are global depth ranges extracted from the literature*			

STATE OF DEEP CORAL ECOSYSTEMS IN THE CARIBBEAN REGION: PUERTO RICO AND THE U.S. VIRGIN ISLANDS

Steven J. Lutz[1,2] and Robert N. Ginsburg[1]

I. INTRODUCTION

This chapter summarizes published and unpublished information on deep corals in the wider Caribbean region (Caribbean Sea and Bahamian Archipelago) including those in the exclusive economic zone (EEZ) of United States Possessions. It summarizes the occurrences of the corals, associated species and their sea floor accumulations; it provides basic information on the geography, geology and oceanography of the region and how they interact to produce sea floor elevations; and it discusses stressors, including potential fisheries interactions.

For the purposes of this chapter deep corals are defined as those in waters below 100 m.

The territorial jurisdiction of the U.S. in the Caribbean is limited to the areas around Puerto Rico, the U.S. Virgin Islands and the uninhabited island of Navassa between Cuba and Hispaniola, illustrated in Figure 8.1. The EEZ of Puerto Rico and the U.S. Virgin Islands extends from the edge of the territorial waters to 200 nautical miles to the north and is bounded to the south by the EEZ of Venezuela, to the east by the British Virgin Islands and to the west by Dominican Republic. The EEZ of Navassa Island is bounded to the north by Cuba, to the west by Jamaica and to the east by Haiti.

As information on deep-sea corals in the U.S. Caribbean is limited, a consideration of the wider Caribbean enables a broader understanding of reported and potential deep water corals in the U.S. Caribbean.

Regional Deep-sea Research

Louis F. de Pourtalès first discovered deep-sea life in the region, including deep-water corals, in the 1860's. Pourtalès, a scientist aboard the Coast Survey steamer *Bibb*, found evidence of life off Cuba at 945 m (3,100 ft). He studied regional deep-sea corals and published comprehensive works (Pourtalès 1867, 1871). Pourtalès was also a pioneer of deep-sea dredging, a method that was used by later research cruises. These cruises were not focused on deep-sea corals and recovered specimens were incidental findings. Since the discoveries made by Pourtalès and the *Bibb* many research cruises have contributed to the understanding of deep-sea corals. Early cruises included voyages by the U.S. Coast Survey vessel *Blake* (late 1870's), U.S. Fish Commission *Albatross* (1880's) and the H.M.S. *Challenger* (1872-1876). Later research cruises included voyages by the R/V *Oregon* and R/V *Oregon II* (1950's to 1970's), R/V *Gerda* (1960's), R/V *Pillsbury* (1960's and 70's), the R/V *Eastward* (1970's), the R/V *Akademik Vernadski* (early 1970's); and R/V *Columbus Iselin* (1970's and 80's).

Beginning in the 1970's, dredging was supplemented by the use of research submersibles. These direct observations and photographs of deep-sea coral communities provided a major advance in understanding the occurrences, morphology and communities of deep-sea corals in the Straits of Florida and off the northeast slope of the Little Bahama Bank (Figure 8.1) (Neumann and Ball 1970; Neumann et al. 1977; Messing 1990; Reed et al. 2005). Other submersible research of the region includes the following: to 300 m (the "sub reef habitat") at Discovery Bay Jamaica (Lang 1974; Hartman 1973; Lang et al. 1975); to 300 m in Belize (Ginsburg and James 1979); research by Harbor Branch Oceanographic Institute (HBOI) to 1,000 m for sites in the Greater and Lesser Antilles and Netherlands Antilles (Reed pers. comm.).

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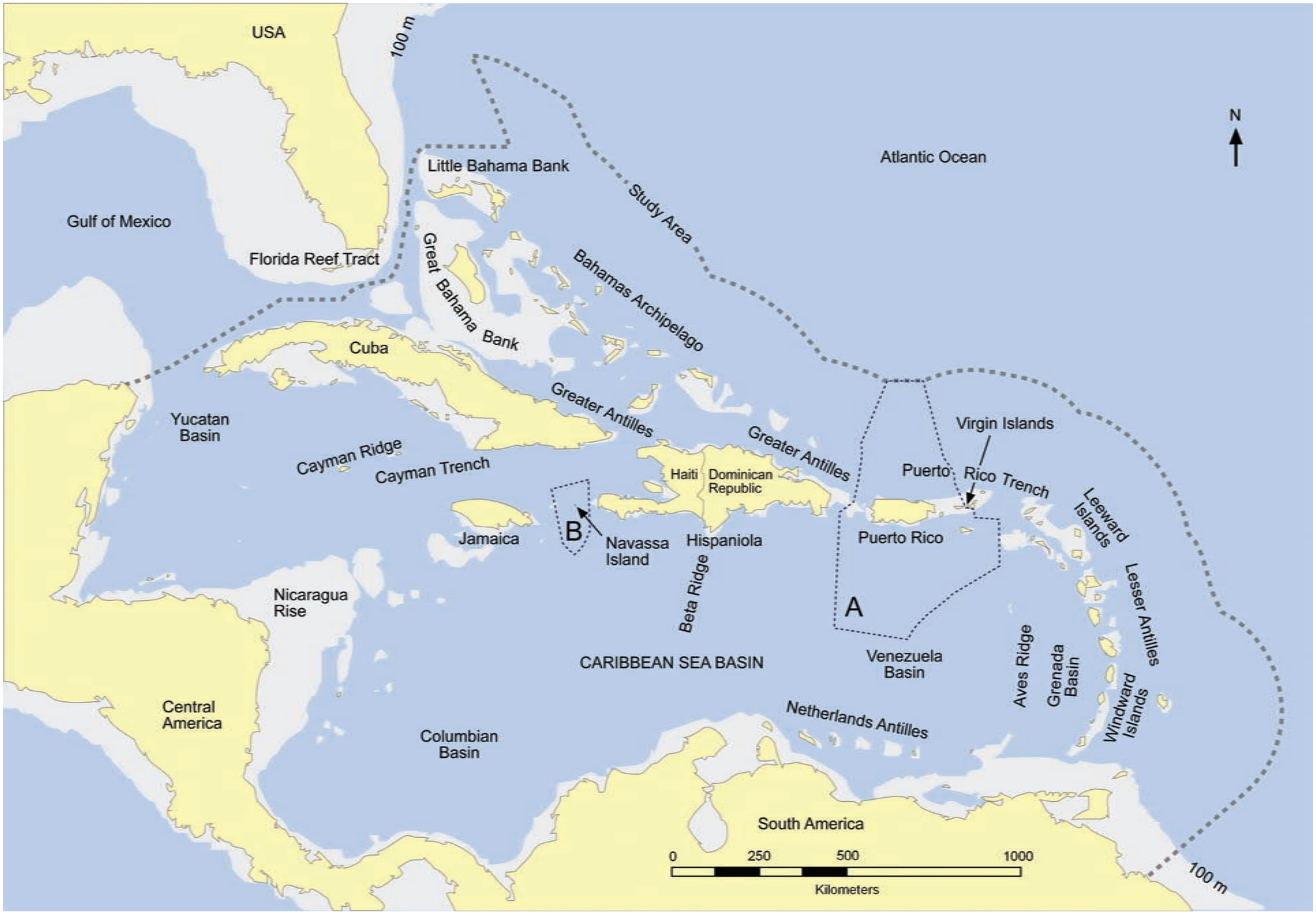


Figure 8.1. Study area showing geography and United States territories. The approximate boundaries of U.S. Caribbean EEZs are identified by the blue dashed line: A) Puerto Rico and the U.S. Virgin Islands; B) Navassa Island.

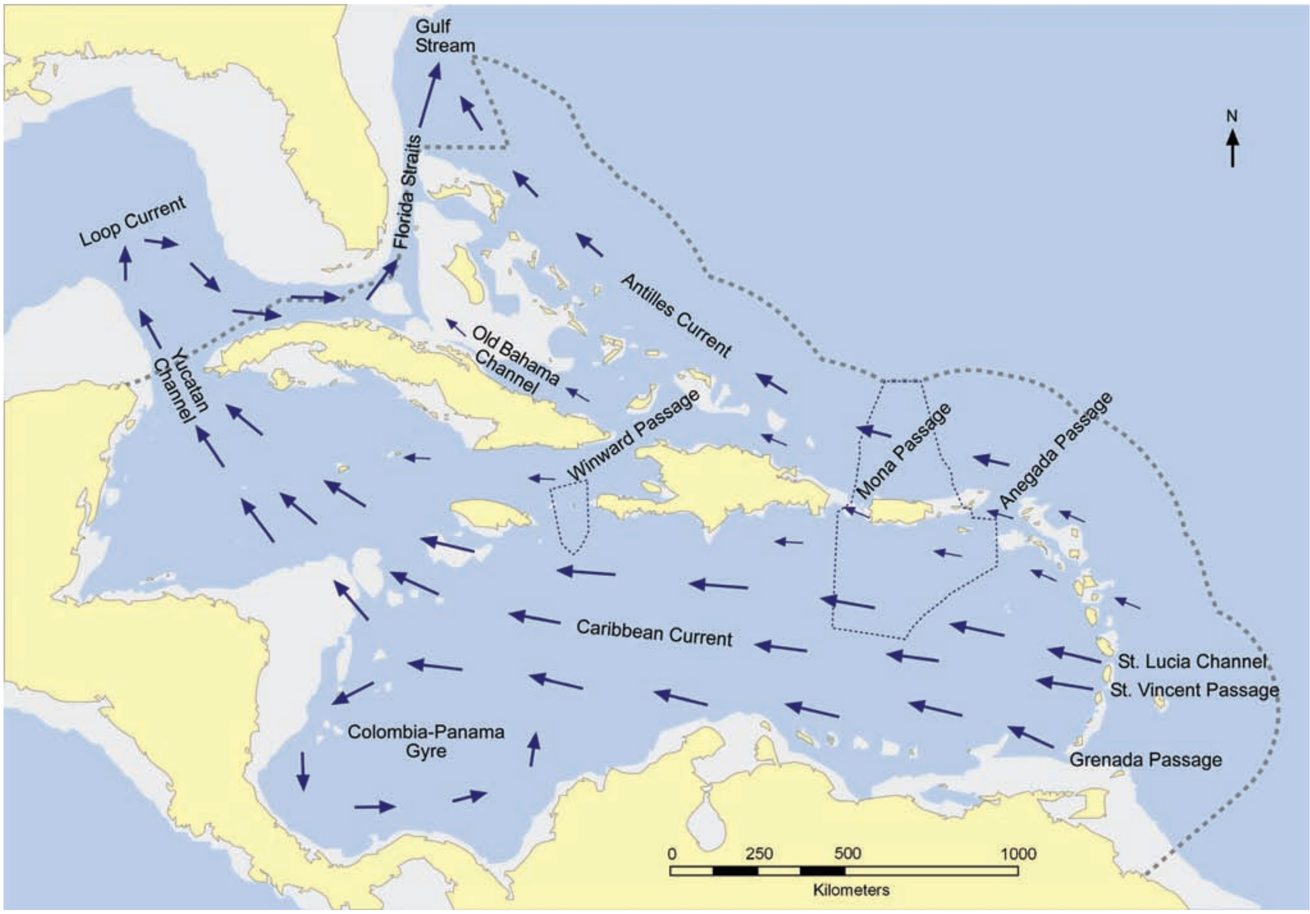


Figure 8.2. Regional currents, channels, and passages (adapted from Gyory et al. 2005a and b).

Submersible research for the U.S. Caribbean includes dives by HBOI and NOAA (Nelson and Appeldoorn 1985).

In 1979 Stephen Cairns published a seminal review of deep-water stony corals occurring in the Caribbean Sea and adjacent waters, examining eighty-eight species of deep-water corals (both solitary and colonial species) (Cairns 1979).

Recent regional deep-sea, coral related, investigations include the following: research on the distribution of deep water coral mounds in the Straits of Florida by the use of high-resolution multibeam sounding (Correa et al. 2006; McNeill 2006); continued private pharmaceutical research throughout the region and especially in the Straits of Florida interests (Reed pers. comm.); research on azooxanthellate coral communities in Colombia's Caribbean waters, off the San Bernardo-Rosario and Santa Marta Islands (Reyes et al. 2005; Santodomingo et al. 2006); and an ongoing effort to characterize seafloor habitats down to 1,000 meters within the U.S. Virgin Islands and Puerto (NOAA 2007).

II. GEOLOGICAL SETTING

The Caribbean Sea basin, the islands within it, and the Bahamas Archipelago, consisting of shallow banks and inter-bank depressions, make up this region (Figure 8.1). While most of the area is centered on the Caribbean plate several continental plates meet in this region, which are hotspots for seismic activity. Interactions between the Caribbean plate, North American plate and the South American plate produced the major topographic features and allow the Caribbean basin to be divided into four smaller basins; the Yucatan, Colombian, Venezuelan and Granada basins (Figure 8.1).

Both tectonic activity and biological activity produce features significant to deep water corals in this region. Tectonic activity is responsible for deep water trenches, ridges, basins and inter-island passages and channels (topographic features are detailed in section III). Products of biological activity include deep coral mounds and lithoherms (discussed in section IV).

III. OCEANOGRAPHIC SETTING

The Caribbean Sea is approximately 2,640,000 km^2 or 1,425,485 square nautical miles. It is a semi-enclosed basin, bounded on the west by Central America, on the south by Central and South America, on the east by the Lesser Antilles and on the north by the Greater Antilles. With a few exceptions, the Caribbean Sea generally exceeds 1,830 m (6,000 ft) in depth with many sections exceeding 3,660 m (12,000 ft) in depth. Its greatest known depth is 7,535 m (24,721 ft) below sea level in the Cayman Trench located between Cuba and Jamaica. The Puerto Rican Trench, the deepest area within the study region and deepest part of the Atlantic Ocean, lies north of Puerto Rico just outside the Caribbean, with a depth of 9,200 m (30,183 ft). The only notable extensive shallow areas are the Bahamas Banks and the Nicaragua Rise. Several gaps between islands on the north and east are major channels and passes for ocean currents connecting the Caribbean Sea with the Atlantic Ocean and Gulf of Mexico. Chief among these are the Windward Passage between Cuba and Hispaniola; the Mona Passage between Puerto Rico and Hispaniola; the Anegada Passage south of the Virgin Islands; smaller channels between islands in the Windward Island chain; and the Grenada Passage between the Lesser Antilles and the South American continent (Figure 8.2).

As a result of the exchanges with the open Atlantic, there is little seasonal variation in surface water temperatures, with a general range from 25.5^o C in the winter to 28 ^{o} C in the summer. Below the surface, water structure is highly stratified in the upper 1200 meters; weakly stratified between 1,200 and 2,000 meters and uniform below 2000 meters. This stratification is directly related to the shallow depth of passages between the Lesser Antilles. They act as sills and impede deep-water flow into the Caribbean (Gordon 1967; Gyory et al. 2005a).

Most water flows into the Caribbean Sea from the Atlantic through the Grenada, St. Vincent and St. Lucia Passages in the southeast (Figure 8.2) (Johns et al. 2002; Gyory et al. 2005a). From these passages, water flows clockwise across the Caribbean Sea basin as the Caribbean Current, the main surface circulation in the Caribbean Sea. It reaches high surface velocity (70 cm/sec) along the Netherlands Antilles and adjacent coastline of South America (Fratantoni 2001). The current then flows to the northwest, over the Colombian basin, towards the Nicaragua Rise and a trough southwest of Jamaica, with a branch forming an counterclockwise Panama-Colombia Gyre (where the current meets Central America). Strong flow (up to 60 cm/sec) has been recorded along the Panamanian and Colombian coasts (Gyory et al. 2005a).

Where currents are diverted by or constricted between landmasses, current velocities increase. The larger and deeper inter island spaces produce major seaways; the more numerous, smaller and shallower ones produce similar but smaller increases in velocity. Current velocities will also increase when water flow meets elevations of the sea floor, typically platforms or banks of calcareous deposits. For example, the passages between the large and long-lived platforms of the Bahamian Archipelago and the Florida Peninsula are sites of increased high flow.

At the Nicaragua Rise channel-like constrictions between shallow banks accelerate current. The flow and water is accelerated through the trough southwest of Jamaica and then turns west as it crosses the Cayman Ridge and enters Yucatan Channel as the Yucatan Current (Gyory et al. 2005d). Strong currents (170 cm/sec) have been reported in the Yucatan Channel (Pillsbury 1890; Gyory et al. 2005d). Water flow exits the Yucatan Channel into the Gulf of Mexico and doubles back as the Loop Current (Gyory et al. 2005c) before entering the Straits of Florida between Western Great Bahama Bank and the Florida Reef Tract where it is joined by waters passing through the Old Bahama Channel to form the Florida Current (Gyory et al. 2005b). Gyory et al. (2005b) reports strong surface flow in the Florida Current; “at times there is a 2 m/sec flow within a few miles of the (Florida) coast.” When this Florida Current exits the Straits it is joined by the Antilles Current and turns eastward and becomes the Gulf Stream *sensu stricto*.

The Antilles Current transports tropical waters from the Atlantic northwestward, flowing north of the Greater Antilles and joins the Gulf Stream off Florida past the outer Bahamas (Figure 8.2) (Rowe et al. 2005). Its waters are concentrated into a strong northward jet centered at 400 meters deep about 80-100 km wide (Lee et al. 1996). It is a considerable source of warm water for the

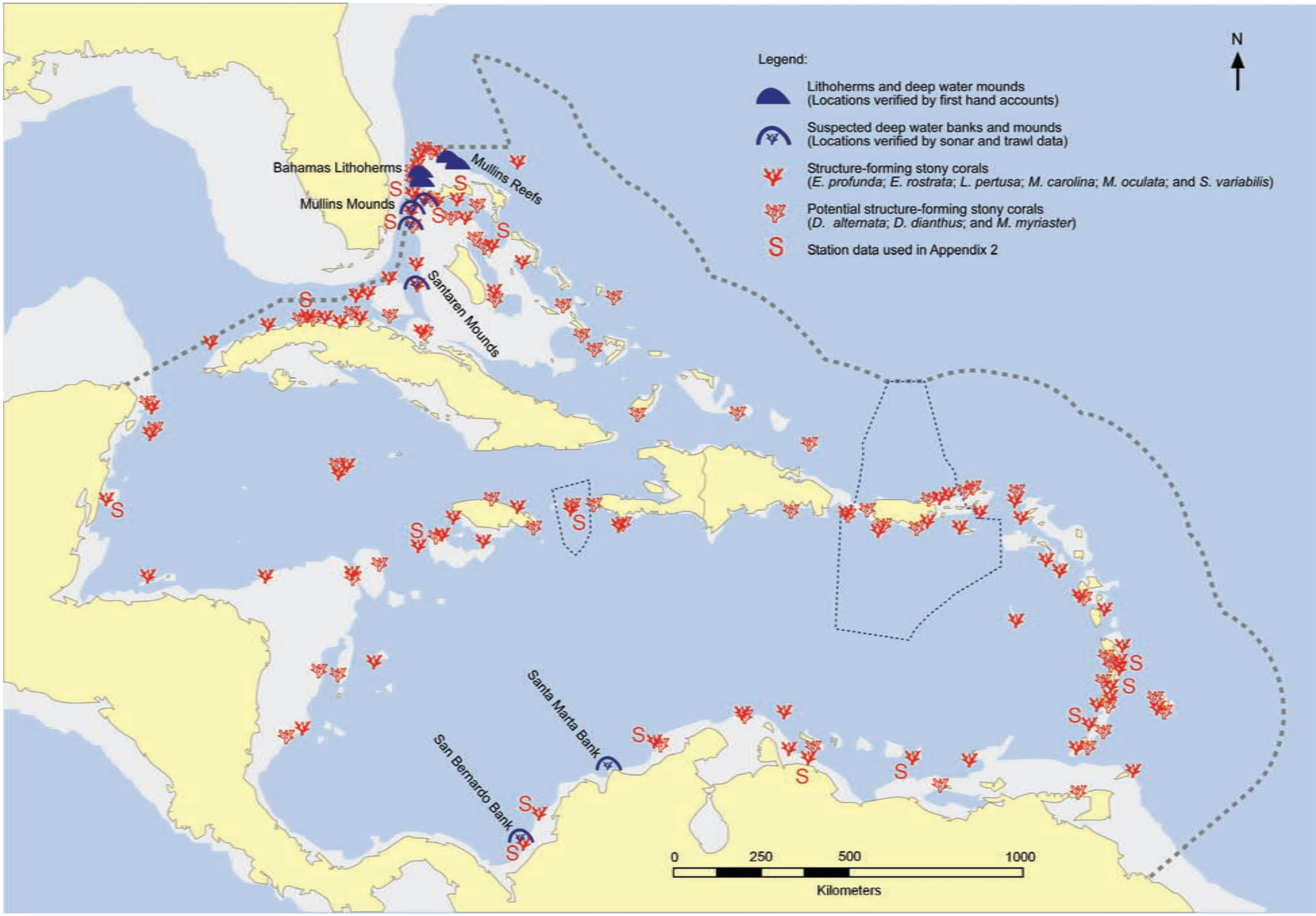


Figure 8.3. Distribution of major and potential structure-forming stony corals (scleractinia) and deep sea bio-buildups (lithoherms, mounds, and banks). The letter S identifies the locations of trawl stations referred to in Appendix 8.2 (some locations overlap). References are listed in Appendix 8.1.

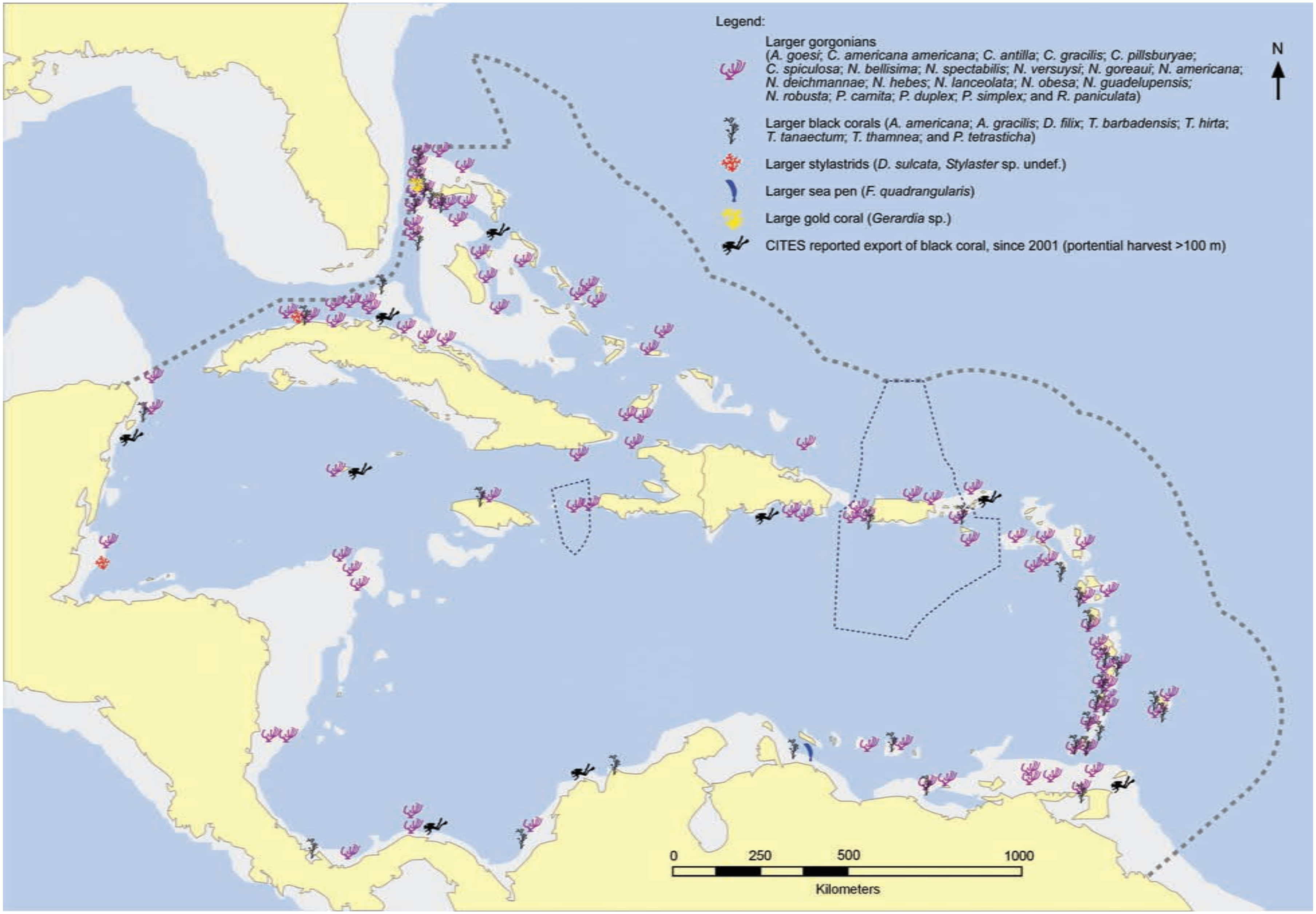


Figure 8.4. Reported distribution of potential habitat-forming corals (larger gorgonians, etc.). References include CITES 2007 and those listed in Appendix 8.1.

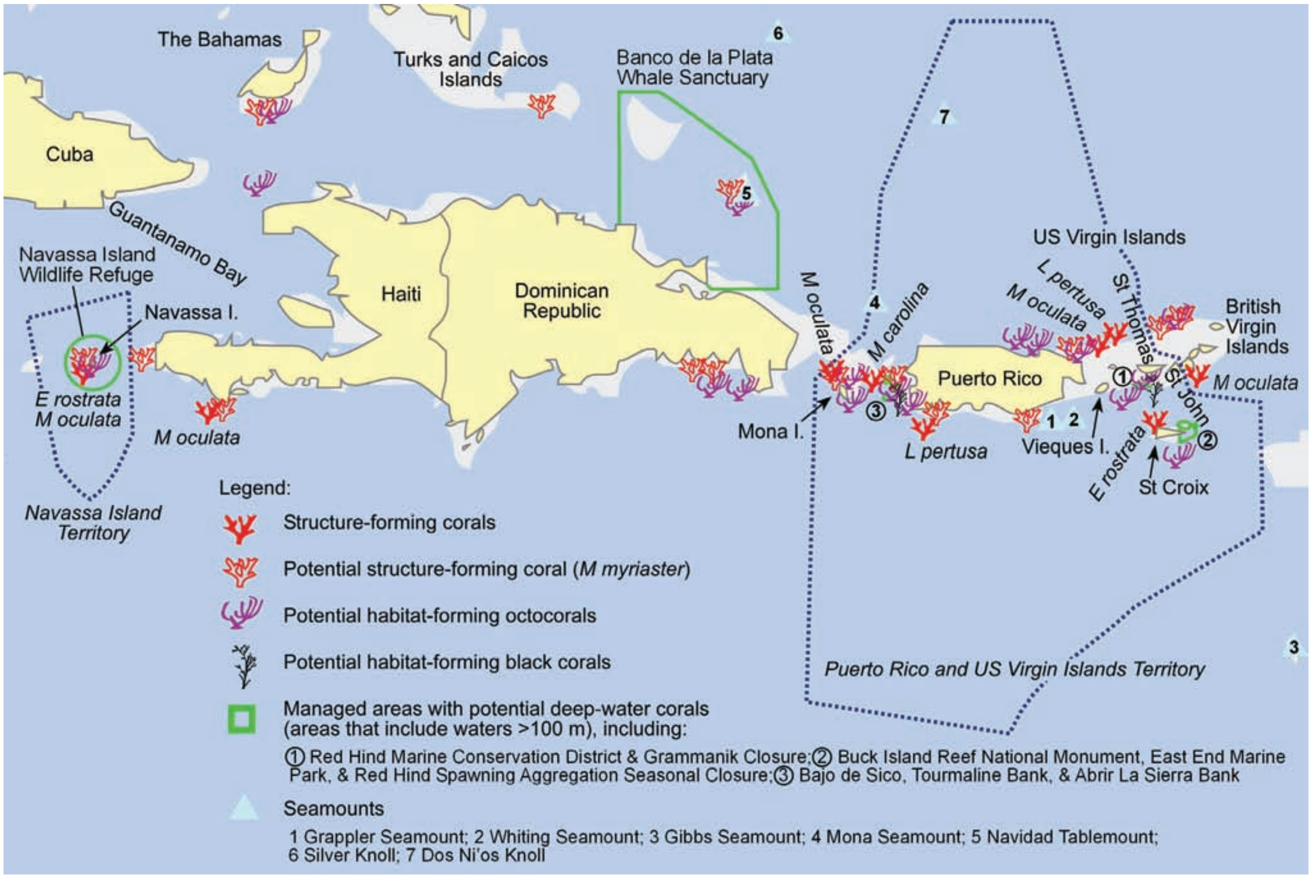


Figure 8.5. Distribution of deep water features and corals found in the U.S. Caribbean and adjacent area. References include EarthRef.org 2007 and those listed in Appendix 8.1.

Gulf Stream system. However, it occurs more as an eddy field along the Bahamas Archipelago rather than as a constant flow (Gunn and Watt 1982).

IV. STRUCTURE AND HABITAT-FORMING DEEP CORALS

A wide variety of deep-sea corals occur within the wider Caribbean region. These include stony corals, gorgonians, soft corals, stylasterids, black corals, lithotelestid coral and sea pens. The knowledge about the distribution of these corals is generally considered poor, greater for some groups than others. Cairns (1979) notes, with regard to deep-sea stony corals, that the southern coasts of the Greater Antilles (Cuba and Hispaniola) and Costa Rica are not well sampled and that the Straits of Florida (including the northwest coast of Cuba) and the Lesser Antilles are well sampled. Many species of deep-sea corals occur within the U.S. Caribbean. Species with an Antillian distribution (occurring within the Greater and Lesser Antilles) may also occur in U.S. Caribbean waters.

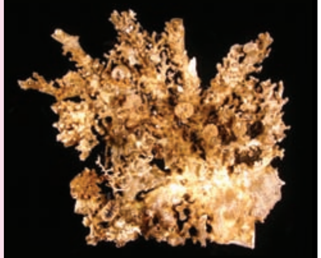
Deep-sea corals of interest to this chapter, are those termed "structure-forming" and "potential habitat-forming". Structure-forming corals are associated with deep-sea coral habitat such as coral banks, bioherms and lithoherms. Both structure and non-structure forming corals occur within the study area (Figures 8.3, 8.4 and 8.5). Bayer (1961) describes the importance of octocorals (gorgonians and soft corals) in the reef building process and framework of shallow reefs. The importance of octocorals in deep water reefs is not yet understood but may be great in terms of contribution to framework and baffling of marine sediment, larger octocorals are expected to contribute and baffle more than smaller species. Appendix 8.1 details the attributes of each coral species including distribution.

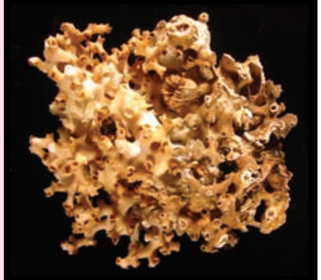
a. *Stony corals* (Class Anthozoa, Order Scleractinia)

Ninety-nine species of azooxanthellate hard corals are reported from the study area in depths below 100 m. Most are small single polyp species, shaped like cups, which often occur solitarily (e.g. Figure 8.6). Solitary corals are not reported to form significant structures. Nine species of structure-building and branched azooxanthellate hard corals are reported from the study area: *Dendrophyllia alternata*, *Desmophyllum dianthus* (also known as *Desmophyllum cristagalli*), *Enallopsammia profunda*, *Enallopsammia rostrata*, *Lophelia pertusa*, *Madracis myriaster*, *Madrepora oculata*, *Madrepora carolina* and *Solenosmilia variabilis* (Cairns pers. comm.). Table 8.1 and Figures 8.7 - 8.10 and 8.15 describe and illustrate structure-building corals.

Six species of azooxanthellate hard corals are regarded as the major structure-forming species: *E. profunda*, *E. rostrata*, *L. pertusa*, *M. carolina*, *M. oculata* and *S. variabilis*. Two genera (*Lophelia* and *Solenosmilia*) constitute two of

Table 8.1. Structure-forming deep water stony corals of the wider Caribbean region. The measurements given in brackets correspond to the approximate horizontal length for each specimen illustrated.

Species	Description	Illustration
Dendrophyllia alternata	*D. alternata* occurs throughout the North Atlantic. This coral forms bushy colonies up to 1 m in height and has been described as a reef builder. It occurs at depths of 279 - 900 m in the tropical western Atlantic. Regionally, it has been recorded with *M. oculata* and *M. myriaster* (Cairns 1979; Cairns and Stanley 1982; Le Goff-Vitry 2003). [30 cm, specimen recovered at 290.8 m off Curacao]	
Desmophyllum dianthus	*D. dianthus* (also known as *D. cristagalli*) forms densely branched colonies is reported to contribute to reef formation. It occurs globally to 2,460 m and in the tropical western Atlantic from 155 - 1,939 m. Regionally, it has been recorded with *E. profunda*, *L. pertusa*, *M. oculata*, and *S. variabilis (Cairns 1979; Cairns and Stanley 1982; Rogers 1999)*. [10.8 cm, specimen recovered at 597 m off the east coast of Florida]	
Enallopsammia profunda	*E. profunda* occurs globally and is endemic to the western Atlantic. It forms massive bushy colonies, up to 1 m thick, and is regarded a major structure-forming species. It occurs from 403 - 1,748 m and is often associated with *L. pertusa*, *M. oculata* and *S. variabilis (Cairns 1979; Cairns and Stanley 1982; Rogers 1999; Reed 2002; Freiwald et al. 2004)*. [30.7 cm, specimen recovered at 801 m in the Straits of Florida off Cuba]	
Enallopsammia rostrata	*E. rostrata* occurs in the U.S. Caribbean and globally. This coral forms massive bushy colonies and is regarded a major structure-forming species. It occurs from 300 - 1,646 m in the tropical western Atlantic. It is associated with *L. pertusa* on deep-water reefs in the north Atlantic and has been recorded with *S. variabilis*, *M. oculata*, and *E. profunda* in the wider Caribbean (Cairns 1979; Rogers 1999; Reed 2002; Freiwald et al. 2004). [31.4 cm, specimen recovered at 1,097 m off Bermuda. Specimen includes *L. pertusa* and *D. dianthus*]	
Lophelia pertusa	*L. pertusa* occurs in the U.S. Caribbean, globally, and is well known from the north Atlantic. This coral forms bushy colonies up to a meter in height and is regarded the most common reef-building deep/cold-water coal. It has been reported from waters as shallow as 25 m to as deep as 3,383 m. Regionally, it is most common between 500 - 800 m. *L. pertusa* is often found associated with *E. profunda* and has been recorded with *D. dianthus*, *M. carolina*, *M. oculata*, and *S. variabilis* in the wider Caribbean (Cairns 1979; Cairns and Stanley 1982; Rogers 1999; Dawson 2002; Reed 2002; Freiwald et al. 2004). [24.3 cm, specimen recovered at 793 m in the Straits of Florida off Cuba]	

Species	Description	Ilustration
Madracis myriaster	*M. myriaster* occurs in the U.S. Caribbean and throughout the wider Caribbean. It forms bushy colonies and is reported as a main framework builder of deep-water coral banks in Colombian waters. Regionally, it has been recorded with *M. carolina*. It occurs from 37 - 1220 m in the tropical western Atlantic (Cairns 1979; Reyes et al. 2005; Santodomingo et al. 2006). [30.2 cm, specimen recovered at 200 m off Jamaica]	
Madrepora carolina	*M. carolina* occurs in the U.S. Caribbean and throughout the tropical western Atlantic. This coral forms bush-like colonies with a thick base and is associated with cold-water reefs as a structure-forming species. It occurs from 53 - 801 m (most commonly between 200 - 300 m). Regionally, it has been recorded with *E. profunda*, *E. rostrata,* and *D. dianthus* (Cairns 1979; Dawson 2002; Freiwald et al. 2004). [27.6 cm, specimen recovered at 333 - 375 m in the northwest Providence Channel off Grand Bahama Island]	
Madrepora oculata	*M. oculata* occurs in the U.S. Caribbean and globally. This coral forms large bushy colonies and is regarded a major structure-forming species. It occurs from 55 - 1,950 m. It is commonly associated with *L. pertusa* in the eastern and northeastern Atlantic and Mediterranean Sea. Regionally, it has been recorded to occur with *E. profunda*, *E. rostrata, D dianthus, L. pertusa*, and *S. variabilis* (Cairns 1979; Rogers 1999; Dawson 2002; Reed 2002; Freiwald et al. 2004). [24.1 cm, specimen recovered at 634 m in the Gulf of Mexico]	
Solenosmilia variabilis	*S. variabilis* occurs globally. This coral forms bushy colonies and is regarded a major structure-forming species. It occurs from 220 - 2,165 m and is known from the northern slope of the Little Bahama Bank from 1,000 - 1,300 m, where it is associated with deep-water banks. It is often found associated with *L. pertusa*, *Madrepora* spp., and *E. profunda*, and has been recorded with *E. rostrata* and *D. dianthus* in the wider Caribbean (Cairns 1979; Mullins et al. 1981; Cairns and Stanley 1982; Rogers 1999; Freiwald et al. 2004). [20.7 cm, specimen recovered at 1,000 m in the North Atlantic Ocean]	

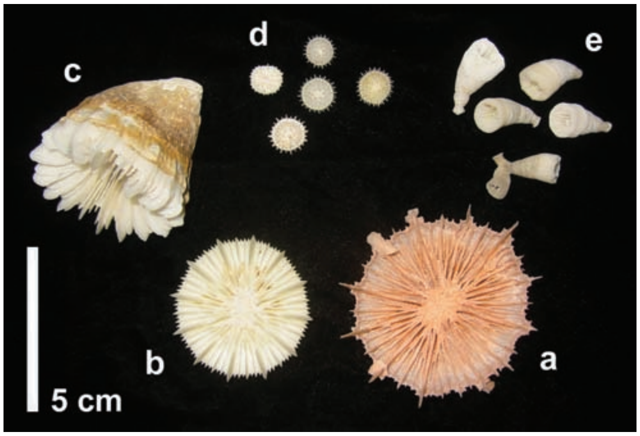


Figure 8.6. Assorted solitary deep water stony corals: a) *Stephanocyathus diadema*, from The Bahamas at 1,779 m; b) *S. laevifundus*, from St. Vincent at 576-842 m; c) *Caryophyllia ambrosia caribbeana*, from Surinam at 1,318-1,343 m; d) *Deltocyathus eccentricus*, from Jamaica at 457-558 m; e) *Bathypsammia tintinnabulum*, from the Straits of Florida at 689-699 m (*B. tintinnabulum* is not known from the region but is presented here for comparison).

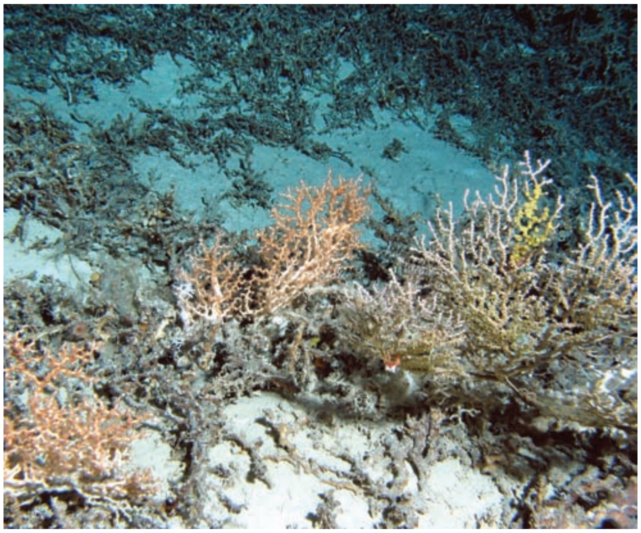


Figure 8.7. Deep sea coral habitat (*M. oculata* and *Paramuricea* sp.) at 2,230 m in the Bahamas (Straits of Florida off Cat Cay). Photo credit: Reed 2006.

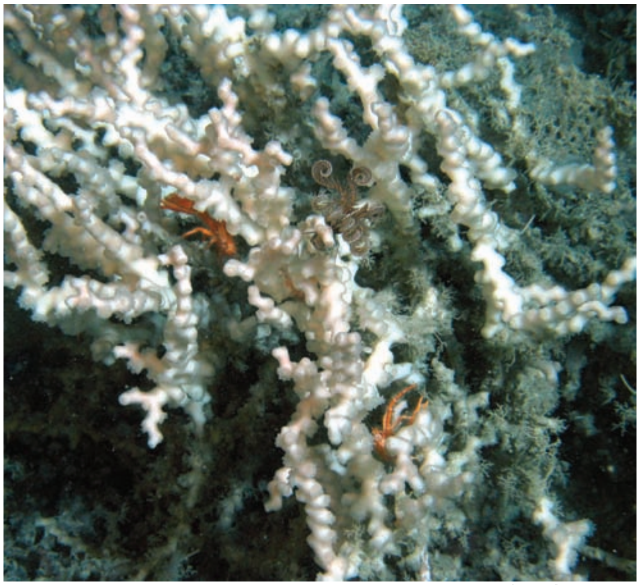


Figure 8.8. Structure-forming coral (*E. profunda*) providing habitat for unidentified crustaceans and a crinoid. Photographed from submersible at 2,721 m in Straits of Florida. Photo credit: Reed 2006

Figure 8.9. Close up of the potential structure-forming coral *D. alternata,* sampled by submersible, from the Netherlands Antilles, at 290.8 m.

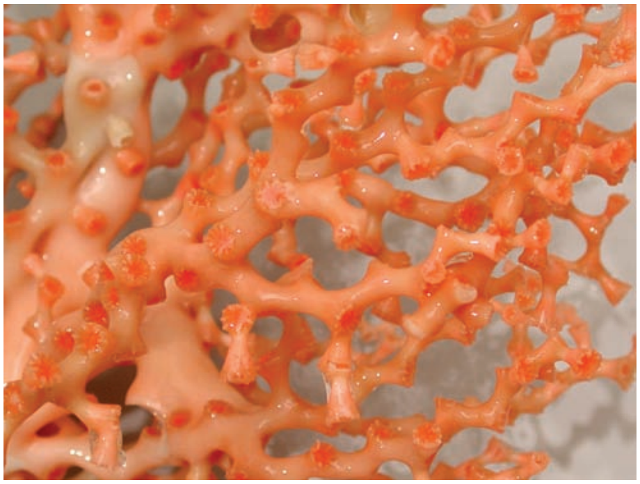


Figure 8.10. Close up of the major structure-forming coral *M. oculata*, sampled by submersible from the Straits of Florida at 746.4 m. Photo credit: Reed 2006.

the four major constituents of known world-wide deep-water coral banks at depths of 400 - 700 m (Cairns and Stanley 1982). Both *M. oculata* and *M. carolina* are regarded as minor constituents of coral banks in the Straits of Florida (Cairns 1979). *Solenosmilia* is the dominant structure-building coral found on deep coral banks north of the Little Bahama Bank (Reed 2002) (Table 8.2, Mullins Reefs), where *Madrepora* and *Enallopsammia* also occur. *Lophelia* and *Enallopsammia* are common components of the lithoherms east of the Little Bahama Bank in the Straits of Florida (Reed 2002) (Table 8.2, Bahamas Lithoherms). Four major structure-forming species *E. rostrata*, *L. pertusa*, *M. oculata* and *M. carolina* have been reported from the U.S. Caribbean.

Another major structure-forming species, *Oculina varicosa*, occurs throughout the Caribbean. *O. varicosa* is a facultative zooxanthellate species (i.e. it occurs with zooxanthellate in shallow water and without in deeper water). *O. varicosa* is reported to 152 m and forms bushy colonies several meters in height (commonly at 45 - 91 m). It is described as a main framework builder of deep-water banks off Florida's central eastern coast. However, as no deep water banks of *O. varicosa* have been reported from the wider Caribbean (only shallow water species) this species is not considered further.

Madracis myriaster, an azooxanthellate stony coral found throughout the wider Caribbean, is reported to form bushy shaped colonies and significantly contribute to habitat formation on

Table 8.2. Scleractinian-dominated coral habitats (“reefs”) of the wider Caribbean. Locations are identified in Figure 8.3.

Location	Description
Mullins Reefs	This site is characterized by a region of deep coral mounds (bioherms) on the northern deep shelf edge of the Little Bahama Bank at depths of 1000-1300 m. Mounds 5-40 m in height are reported. The bioherms are dominated by the major structure forming deep water coral *Solenosmilia* sp., *Lophelia* is reportedly absent. An area of approximately 1500 km^2 is described. Site profiled via. submersible, seismic reflections, and dredges (Mullins et al. 1981; Reed 2002).
Bahamas Lithoherms	This site is characterized by a region of lithoherms on the western shelf edge of the Little Bahama Bank in the Straits of Florida at depths of 300-500 m. Pinnacles 30-50 m in height are reported. The lithoherms are dominated by the major structure forming deep water coral *L. pertusa*. *E. profunda* and *M. oculata* are also present. *D. alternata*, *A. fecunda*, and the larger black coral *Distichopathes filix* have been reported from the region. An idealized lithotherm from this site is illustrated in Figure 8.23. Wreckfish have been reported in association with these lithoherms. An area of approximately 330 km^2 is described. Site profiled via. submersible, seismic reflections, and dredges (Neumann and Ball 1970; Neumann et al. 1977; Messing et al. 1990; Reed 2002).
Mullins Mounds	Deep-water mounds (banks and lithoherms) and cemented hardgrounds are described off Bimini and entering the New Providence Channel. The mounds are described to continue northward and connect to the Bahamas Lithoherms. Site profiled via. coring and seismic reflections (Mullins and Neumann 1979).
Santaren Mounds	Deep water mounds are described at 500-800 m along the western shelf edge of the Great Bahama Bank, running from the Santaren Channel to the Straits of Florida. Mounds >30 m were reported. Site profiled via. multi-beam side scan sonar and drop camera (Correa et al. 2006; Grasmueck et al. 2006).
Santa Marta Bank	This site is described as a deep water coral bank on the northwestern shelf of Colombia at a depth of 200 m. The bank is dominated by the potential structure-forming deep water coral *M. myriaster. Anomocora fecunda*, *Coenosmilia arubuscula*, and *Polymyces fragilis* were reported abundant. Black corals and octocorals were reported numerous and include *Antipathes columnaris*, *Elatopathes abetina*, *Sticopathes* spp., *Chrysogorigia desbonni*, and *Nicella guadalupensis*. Site profiled via echosounding and dredges (Reyes et al. 2005).
San Bernardo Bank	This site is described as a deep water coral bank on the northern shelf of Colombia at a depth of 155-160 m. The bank is dominated by the potential structure-forming deep water coral *M. myriaster*. Other species considered to contribute to habitat include *A. fecunda*, *C. arubuscula*, *Eguchipsammia cornucopia*, *M. oculata*, *Javania cailleti*, *Caryophyllia berteriana*, *P. fragilis*, *Thalamophyllia riisei*, *Oxysmilia rotundifolia*, and other *Madracis* species. Flounder, basslets, and scorpionfish were the most abundant species of fish recovered. *Madracis* thickets and coralline mounds (up to 10 m in height) are reported. Site profiled via. echosounding, dredges, and grab sampling (Reyes et al. 2005; Santodomingo et al. 2006).

deep-water coral banks off Colombia (Reyes et al. 2005; Santodomingo et al. 2006). Investigations with sonar profiling and trawl and grab sampling suggest deep water banks from two locations off Columbia’s continental shelf at depths of 155 - 200 m; Santa Marta and San Bernardo Banks. Table 8.2 details these locations. Relief, “suggestive of reef structures”, was reported. *M. myriaster* occurs in the U.S Caribbean (Figure 8.5). Reyes et al. (2005) also report a shallower azooxanthellate coral community off Colombia at a depth of 70 m. *Cladocora debilis* was noted as the main matrix builder of this community. As this community occurs at less than 100 m in depth, *C. debilis* is not considered further.

Two other potential structure-forming species, *D. alternata* and *D. dianthus* are found throughout the wider Caribbean, but have not been reported from the U.S. Caribbean. *D. alternata* is found throughout the North Atlantic and forms bushy colonies to 1 m in height. It has been described as a reef builder (Le Goff-Vitry 2003) and has been recorded with *M. oculata* and *M. myriaster* in the wider Caribbean. *D. dianthus* is reported to form densely branched colonies and to “contribute to

Figure 8.11. Large deep-sea black coral (*Leiopathes glaberrima*) recovered from 304 m in the North Atlantic (approximately 116 cm in height).

Figure 8.13. Bubblegum coral (*Paragorgia johnsoni*) sampled by submersible from 620 m west of the Little Bahama Bank in the area of Bahamas Lithoherms (approximately 51 cm in height). Photo credit: Amy Wolfrum.

Figure 8.15. Bamboo coral (*Keratoisis flexibilis*) on deck and utilizing a deep water structure-forming coral (*E. profunda*) as substrate (bamboo coral is approximately 34 cm in height). Coral recovered from 806.5 m by submersible. Photo credit: Reed 2006.

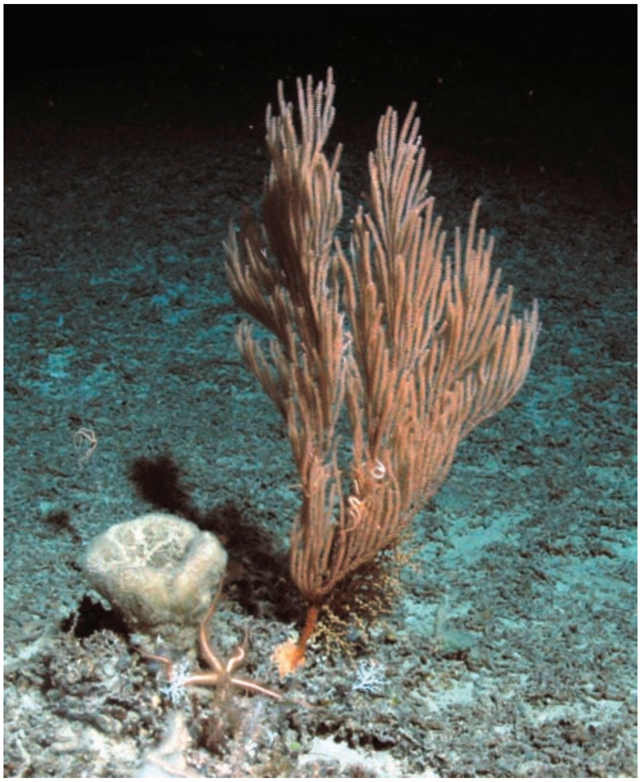


Figure 8.12. Large deep water gorgonian (*Paracalyptrophora* sp.) and deep water sponge (*Pachastrellidae* sp.). Photographed from submersible at 2,193 m in The Bahamas (Straits of Florida) (gorgonian is approximately 53.5 cm in height). Photo credit: Reed 2006.

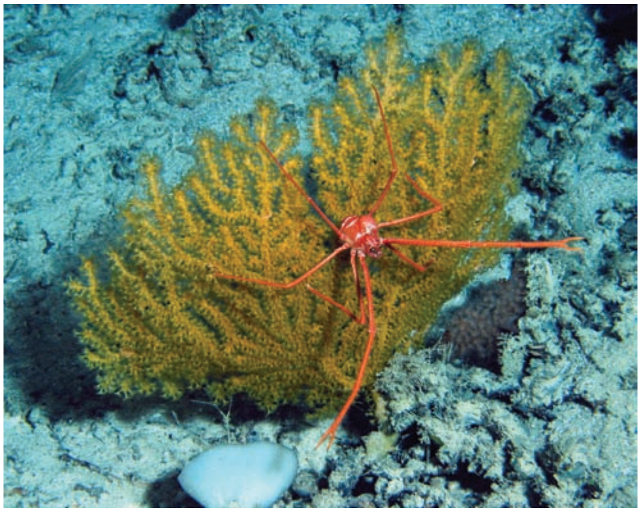


Figure 8.14. Large deep water gorgonian (*Paramuricea* sp.) providing habitat for an unidentified crustacean. Photographed from submersible at 2631 m in The Bahamas (Straits of Florida off Cat Cay) (gorgonian is approximately 33 cm in width). Photo credit: Reed 2006.

Figure 8.16 Large deep water gorgonian *Nicella americana*, collected from 165 m off the Dominican Republic (approximately 53 cm in width).

reef formation" (Cairns and Stanley 1982). *D. alternata* and *D. dianthus* are detailed in Table 8.2.

The distribution of major and potential structure-forming species in the study area generally follows the Antillian arc and the margins of the continental shelves of South and Central America (Figure 8.3).

b. Black corals (Class Anthozoa, Order Antipatharia, Families Cladopathidae and Schizopathidae)

Approximately thirty-two species of antipatharia are reported from the wider Caribbean in depths below 100 m, with thirteen considered potentially important habitat-forming species. Eight species are reported from the U.S. Caribbean, with five considered potentially important habitat-forming species: *Antipathes americana*, *A. caribbeana*, *Plumapathes pennacea*, *Tanacetipathes hirta*, *Parantipathes tetrasticha*. Opresko and Sanchez (2005) list two regional black coral species of commercial importance: *A. atlantica* and *A. gracilis.* Both species are considered potentially habitat-forming. The maximum reported height of deep water antipatharians occurring in U.S. Caribbean waters is 61 cm (*P. tetrasticha*). Figure 8.11 illustrates a large deep-sea black coral.

c. Gold corals (Class Anthozoa, Order Zoanthidea)

One species of gold coral is reported from the Caribbean region. Messing et al. (1990) describe a large zoanthidean tentatively identified as *Gerardia* sp. in Bahamian waters. This species is considered habitat-forming as colonies 1 m tall and 1.5 m across were reported. *Gerardia* sp. was found in dense stands on lithoherm crests, where current flow was the greatest.

d. Gorgonians (Class Anthozoa, Order Gorgonacea)

Approximately one hundred and forty-seven species of gorgonians are reported from the wider Caribbean at depths below 100 m. Thirteen species are reported from the U.S. Caribbean (more are expected). Forty-four species are considered potential habitat-forming species, with twelve occurring in U.S. Caribbean waters: *Acanthogorgia goesi*, *Callogorgia americana Americana*, *Diodogorgia nodulifera*, *Ellisella barbadensis*, *E. elongata*, *Narella bellissima*, *N. pauciflora*, *N. deichmannae*, *N. obesa*, *N. guadelupensis*, *Riisea paniculata* and *Swiftia exserta*. The maximum reported height of a wider Caribbean deep water gorgonian is 300 cm (*Pseudoplexaura porosa*), and 244 cm for U.S. Caribbean waters (*E. barbadensis*). Two species of red or pink corals (family Coralliidae); 13 species of bamboo coral (family Isididae); one species of bubblegum coral (family Paragorgiidae); and 34 species of red tree coral (family Primnoidae) are known from the region. Detailed distribution data (beyond occurring in the western Atlantic) was available for only 54% (82) of known deep water gorgonians. Height and/or width data was available for 34% (50) of known deep water gorgonians. It is expected that many more gorgonians are potential habitat-forming species. Figures 8.12 - 8.16 and 8.17 illustrate deep-sea gorgonians.

Figure 8.17. Deep water coral habitat at 829.4 m in The Bahamas (Straits of Florida). A variety of deep-sea corals are illustrated, including the soft corals *Anthomastus agassizi* (red in color) and *Pseudodrifa nigra* (brown in color). Photo credit: Reed (2006).

Figure 8.18. Sea pens (*Renilla reniformis*), from Curacao, Netherlands Antilles (each approximately 2 cm in width). This species occurs to 108 m or more.

e. *True soft corals* (Class Anthozoa, Order Alcyonacea and Suborder Stolonifera)

Twenty species of true soft corals (Alcyonacea) are reported from the wider Caribbean in depths below 100 m. Only one is considered a potentially important habitat-forming species; *Neospongodes portoricensis*, with a maximum reported height of 30 cm. Only one is reported from the U.S. Caribbean: *Stereotelesto corallina*. Detailed distribution data was available for 35% (7) of known deep water alcyonaceans. Figure 8.17 illustrates a deep-sea soft coral.

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

Pennatulaceans, or sea pens, live in soft-sediment and are known to form extensive groves in some areas (Morgan et al. 2006). Eight deep-water sea pens are reported from the wider Caribbean. One species is reported from the U.S. Caribbean: *Renilla reniformis*, with a maximum reported height of 6.5 cm it is not considered an important habitat-forming species (illustrated in Figure 8.18). It is bioluminescent. The maximum reported height of a deep water pennatulacean occurring in the wider Caribbean is 210 cm, for *Funiculina quadrangularis*. According to Picton and Howsen (2002) *F. quadrangularis* is often found in very large colonies. This order contains the deepest deep-sea corals, many occur below 1,000 m, with one species (*Umbellula magniflora*) reported from 6,300 m in the Caribbean Sea basin. Most deep water sea pens are found on basin floors, rises and trenches throughout the Caribbean region including the Caribbean Sea basin, Aves Ridge and Puerto Rico and Cayman Trenches. Height and width data were available for 25% (2) of known deep water sea pens.

Figure 8.19. Large deep water stylasterid (*Distichopora sulcata*) dredged off Havana, Cuba (approximately 33 cm in width).

Figure 8.20. Deep-sea stylasterid (*Stylaster miniatus*) providing substrate for a solitary deep water stony coral (*Paracyathus pulchellus*) and other unidentified invertebrates, the Straits of Florida, at 191 m (stylasterid is approximately 10 cm in width).

g. *Stylasterids* (Class Hydrozoa, Order Anthoathecatae, family Stylasteridae)

Forty-one species of stylasterids are reported from the wider Caribbean at depths below 100 m. Only one is regarded as a potential habitat-forming species; *Distichopora sulcata* (Figure 8.19), with a maximum reported height of 25 cm and width of 30 cm, endemic to the waters off northwest Cuba. However, additional larger stylasterids are likely - during a submersible dive James and Ginsburg (1979) recorded a larger unidentified stylasterid measuring “about 30 cm across” growing out from a rock wall at 290 m off Belize Glovers Reef). Fifteen smaller (non habitat-forming) species (<25 cm in height or width) occur in U.S. Caribbean waters. All wider Caribbean stylasterids are referenced by Cairns (1986).

Puerto Rican waters contain two stylasterid species: *S. atlanticus* and *S. spatula*. Stylasterids have been recorded with many other species of deep water corals and can serve as substrate allowing invertebrates to gain a foothold (Figure 8.20).

Deep Coral Habitat Types

Deep sea corals often occur as individual and/or scattered colonies on the sea floor (Cairns 1979, 2000). More numerous colonies can form clumps or thickets of varying density (Mullins et al. 1981; Messing et al. 1990) (Figures 8.7, 8.8 and 8.10). These bush-like aggregations can form habitat on suitable substrate and contribute to the formation of deep sea bio-buildups through their skeletal debris and by trapping pelagic sediment. Two types of deep-sea bio-buildups are reported from the wider Caribbean region (deep coral mounds and lithoherms); their morphologies and compositions, and deep-sea coral banks are discussed below. Seamounts are also discussed.

Deep Coral Mounds

A variety of terms have been used for the unconsolidated sea floor elevations with which deep-sea corals occur. In general these structures are described as "capping mounds of unconsolidated sediment and coral rubble, which are often built on an underlying lithified substrate"

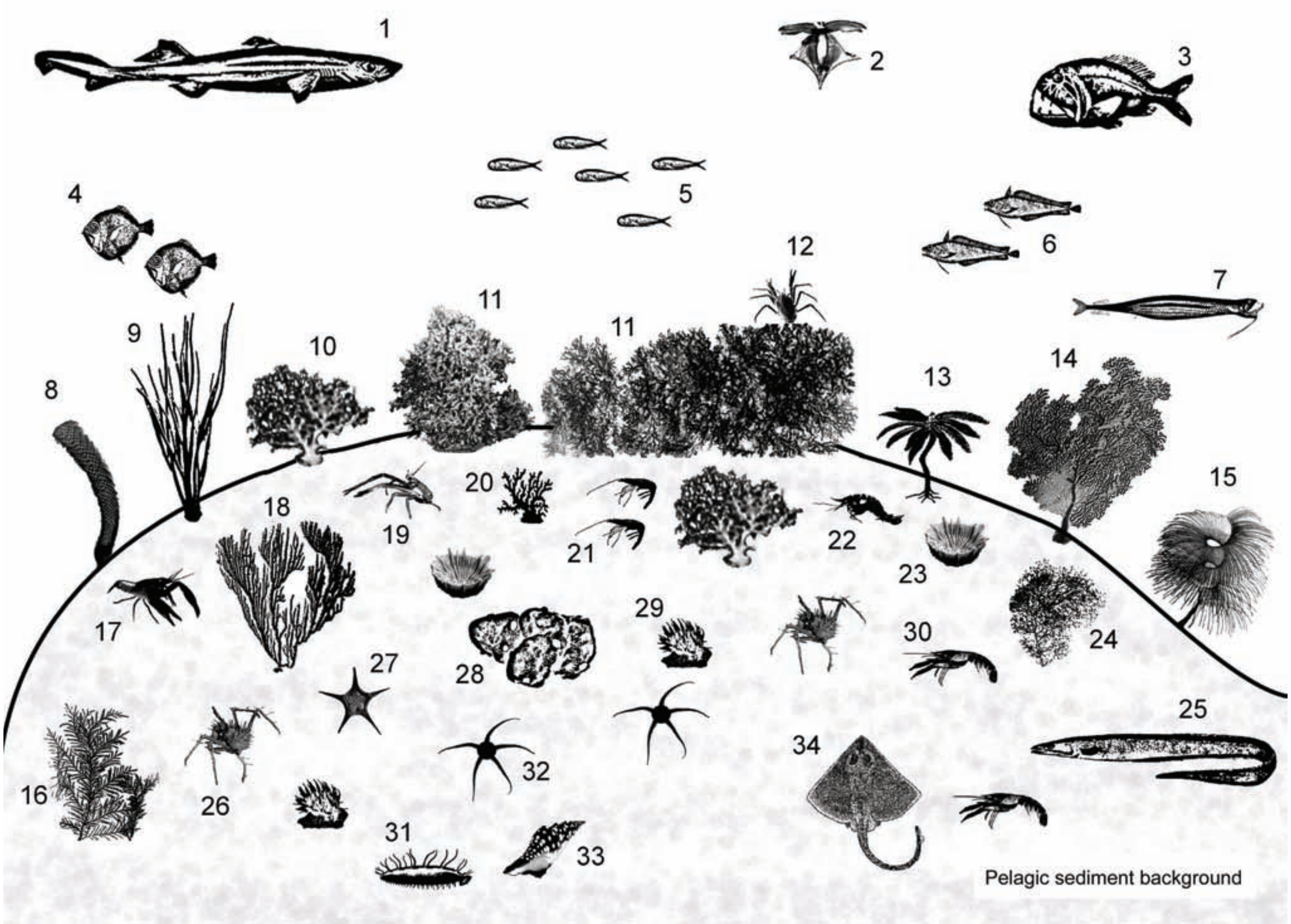


Figure 8.21. Idealized regional deep coral mound (not to scale). Associated benthos as follows: 1) *Etmopterus* sp. (dogfish sharks); 2) pteropods; 3) *Brotulid* sp. (fangtooths); 4) *Diretmus* sp. (dorys); 5) *Myctophid* sp. (lanternfish); 6) *Macrouid* sp. (grenadiers); 7) *Stomias* sp. (dragonfish); 8) *Hexactinelida* sp.; 9) *Cirripathes* sp.; 10) *S. varibilis*; 11) *M. oculata*; 12) *Galatheid* sp. (deep-sea crabs); 13) crinoids; 14) gorgonians; 15) *Iridogorgia* sp.; 16) *Antipathes* sp.; 17) *Macruan* sp.; 18) *Keratoisis* sp.; 19) *Munida* sp. (squat-lobsters); 20) *Stylasteria* sp.; 21) *Nematocarcinidae* sp. (deep-sea shrimp); 22) *Glyphocrangon* sp.; 23) solitary corals; 24) *Chrysogorgia* sp.; 25) *Synaphobranchus* sp.; 26) *Lithodid* sp.; 27) *Nymphaster* sp.; 28) porifera; 29) *Alcyonaria* sp.; 30) *Nephropsis rosea*; 31) *Holothurian* sp. 32) *Ophiuroid* sp.; 33) *Turrida* sp.; 34) *Cruriraja* sp. (skates). Sources listed in Appendix 8.2.

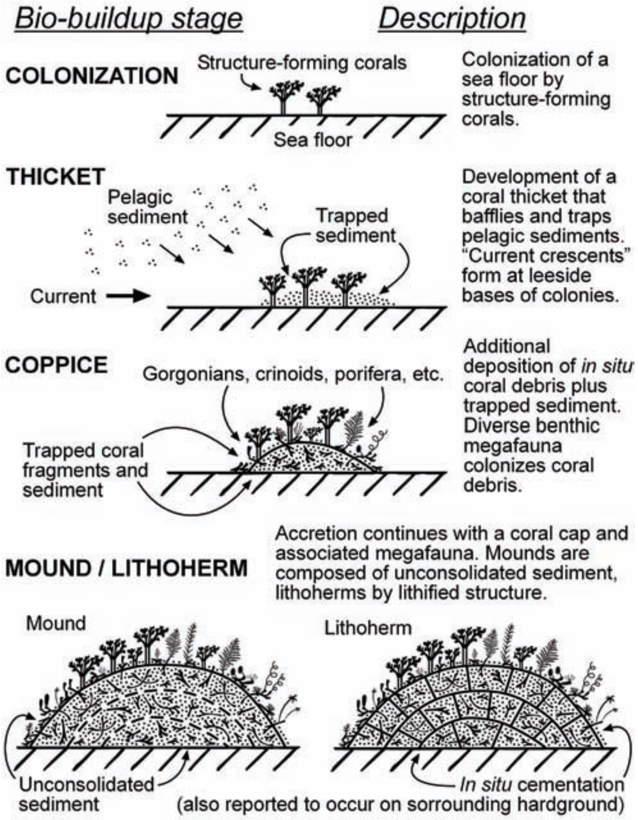


Figure 8.22. Hypothetical development sequence of deep coral mounds (not to scale). Figure adapted from Mullins et al. 1981, based in part on Squires 1964 and Neumann et al. 1977.

(Reed 2002). These structures have been called deep-water coral banks; deep-sea coral mounds; colony thickets; coral thickets; coral structures, deep-water coral reefs; and bioherms (Stetson et al. 1962; Squires 1964; Neumann et al. 1977; Mullins et al. 1981; Reed 2002). The accepted geological term for mounds rich in unbound skeletal debris is biostrome (Bates and Jackson 1987). In what follows we use "deep coral mounds" for this type of buildup.

In the study region these deep coral mounds occur in areas with strong currents and/or upwelling where they accrete by a combination of coral skeletal debris and trapped suspended sediment swept into coral structures (Mullins et al. 1981). The resulting structures range in height over the surrounding sea floor from a few meters to 50 m (Reed 2002).

The most extensive known occurrence of deep coral mounds reported in the Caribbean is found on the northern slope of Little Bahama Bank at depths between 1,000 to 1,300 m (Mullins et al. 1981). Here, where bottom currents were reported to be as much as 50 cm/sec and temperatures of 4-6^{o} C, numerous banks are inferred to occur in an area of 2,500 km^2 with relief over the surrounding sea floor ranging from 5-40 m (ibid). The surface sediments of these mounds consist predominantly of pelagic organisms such as planktonic foraminifera and pteropods, with small amounts of coral skeletal debris and other invertebrates in the coarser grain sizes (ibid). These mounds appear to be developed by the baffling action of the thickets of deep corals that traps pelagic sediments and build on unconsolidated mounds. Other coelenterates found on these mounds include gorgonians, alcyonaceans and antipatharians (Figure 8.21). Mullins et al. (ibid) present a useful schematic model of the sequential development of these mounds (Figure 8.22) based on previous publications (Squires 1964; Neumann et al. 1977). Figure 8.3 illustrates the distribution of deep coral mounds. Table 8.2 details these occurrences.

Lithoherms

In contrast to the unconsolidated deep coral mounds, lithoherms (Neumann et al. 1977; Messing et al. 1990; Reed 2002) are composed of varied communities of benthic organisms growing on successive crust-like layers of friable limestone. Lithoherms have also been referred

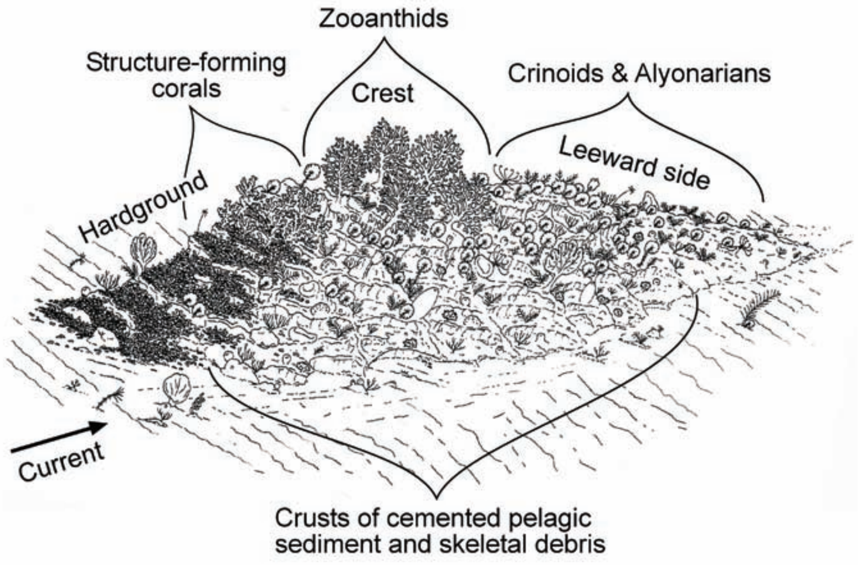


Figure 8.23. Idealized lithoherm of the Straits of Florida (not to scale). Figure adapted from Messing et al. 1990.

to as bioherms, deep-water biohermal buildups and muddy carbonate buildups (Neumann et al. 1977; Reed 2002). Regionally, they are reported only from the eastern side of the Straits of Florida at depths between 500 and 700 m below sea level. According to Messing et al. (1990) the lithoherms are elongate mounds up to 300 m long and 50 m high. Their surfaces show successive friable limestone layers composed of fine-grained carbonate skeletal sediment with variable amounts of coral debris. The cement of the crust-like layers of lithoherms is composed of magnesium calcite with 10-14 mole % magnesium (Wilbur and Neumann 1993).

Messing et al. (1990) describe and illustrate (Figure 8.23) a distinct, tripartite biozonation of one of these lithoherms, which they ascribe to variations in current velocity produced by the mounds, also described by Genin et al. (1986). On the steeper margin or side facing into the current (upcurrent margin) where velocities may reach 100 cm/sec, corals (*L. pertusa*) predominate (“corals” in Figure 8.23). A zone of zoanthids forms along the upcurrent crest (gold coral = “zoanthids” in Figure 8.23) and crinoids and alcyonarians occur behind this zone (“crinoids and alcyonarians” in Figure 8.23) and on the flanks of the lithoherms (Genin et al. 1986). Figure 8.3 illustrates the distribution of known lithoherms. Table 8.2 details these occurrences.

Deep-sea Coral Banks

Reyes et al. (2005) describes two azooxanthellate deep water coral habitats (banks) at depths greater than 100 m off Colombia’s Caribbean shelf. Substrate included hard bottom limestone (fossilized reef) and metamorphic rocks. It is unclear to what extent these corals are building upon themselves (i.e. as with bio-buildups) or simply opportunistically taking advantage of suitable substrate (limestone platform). Reyes et al. (ibid) suggested similarities with shallow water reefs and stated a need for further investigations. Figure 8.3 illustrates the distribution of known deep water coral banks. Table 8.2 details these occurrences.

Seamounts

Deep sea corals are known as intimate associates of seamounts throughout the world (Freiwald et al. 2004; Clark et al. 2007). EarthRef.org (2007) lists four seamounts occurring within the U.S. Caribbean waters: Grappler Seamount; Whiting Seamount; Mona Seamount; and Dos Ni’os Knoll. Figure 8.5 illustrates their locations. The potential that seamounts throughout the region are home to deep water coral ecosystems deserves further attention.

Relevant Geological and Oceanographic Processes

Five processes play significant roles in the distribution and composition of bio-buildups: (1) foremost is amplification of current velocities by submarine topography; (2) the biological production of skeletal debris; (3) physical trapping and stabilization of sediment by thickets of corals, sponges and alcyonarians to build elevated accumulations; (3) availability of hard substrate for recruitment of corals; and (4) the submarine cementation that produces lithoherms. Process 3 is the most significant for deep water banks.

Increased current velocities appear essential for flourishing deep corals both because they can locally sweep away sediment to expose the hard substrate that encourages settlement of coral larvae and they provide a supply of plankton on which the corals feed. In addition, increased currents bring a continued supply of pelagic sediment to help build local relief (mounds and lithoherms).

Two kinds of submarine topography can accelerate current velocities. One, where water flow meets or is constricted between land masses, for example, the seaways or channels between islands of the Lesser Antilles or Windward Islands (Figure 8.2). The larger and deeper inter island spaces produce the major seaways; the more numerous, smaller and shallower ones produce similar but smaller increases in velocity. A second kind of topographic constriction occurs when water flow meets elevations of the sea floor, typically platforms or banks of calcareous deposits. The spaces between large and long-lived platforms of the Bahamian Archipelago and the Florida Peninsula are sites of increased flow velocities between adjacent platforms. A smaller scale example of topographic constriction of currents is present in the series of shallow banks of calcareous deposits, which have developed on the Nicaragua rise and channel flow from the Caribbean Sea contributing to the initiation of the swift Yucatan Current. Localized sediment accumulation, either physical or as a result of the trapping by thickets of erect invertebrates, is needed to produce sea floor relief.

The role of hard substrate in initiating coral settlement is ambiguous. On the one hand it is repeatedly cited as necessary for settlement of coral larvae (Freiwald et al. 2004, pp. 18, 21). However, in the same publication (ibid, pp 27-28) occurrences are cited of deep-sea corals on mounds, which presumably are unconsolidated sediment. Mullins et al. (1981) described and illustrated a compelling example of corals growing on mounds of unconsolidated pelagic sediment from the margin of Little Bahama Banks. One explanation for this apparent contradiction may be the minimal size of hard substrate required to promote settlement. If for example, something as small as a bivalve shell is sufficient then deep-sea corals could establish on mounds of unconsolidated sediments that included bivalve skeletons. Once a few corals are established their continued production of skeletal debris provides continually expanding hard substrate for larval settlement (Figures 8.15 and 8.20 illustrate the substrate use of deep-sea corals). Syndepositional, subsea cementation triggered perhaps by persistent strong currents (Straits of Florida) is required to produce current-resistant lithoherms and it may also be responsible for developing hard substrates on which deep coral mounds develop.

V. SPATIAL DISTRIBUTION OF CORAL SPECIES AND HABITAT

The distribution of deep water corals generally follows the Antilles and continental shelves of Central, South and North America (Figures 8.3 - 8.5). Dawson (2002) analyzed the distribution of 129 species of azooxanthellate (deep-sea) stony corals in the Caribbean and surrounding areas. His findings include the following: the greatest diversity of species occurs at around 200-350 m in depth; and the highest diversity of species is located at the northern islands of the Lesser Antilles.

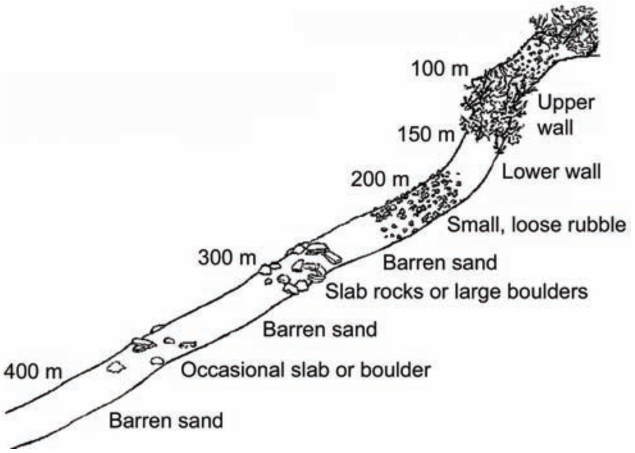


Figure 8.24. Cross-section of a "typical" continental slope for Puerto Rico and the U.S. Virgin Islands to approximately 400 m. Deep-sea research has been limited and, to date, deep corals have been only sporadically reported from the region. Figure adapted from Nelson and Appeldoorn 1985.

To date, no significant deep scleractinian coral habitats have been discovered in the U.S. Caribbean. Deep-sea corals have been reported from submersible and ROV research, but only sporadically. However, deep-sea research for the region is still in its infancy. Previous research includes limited ROV and submersible work off Navassa Island (Littler and Littler 1999, Reed pers. comm.) and limited submersible work off Puerto Rico and the U.S. Virgin Islands (Nelson and Appeldoorn 1985). Figure 8.24 illustrates a cross section of a "typical" continental slope for Puerto Rico and the U.S. Virgin Islands, adapted from Nelson and Appeldoorn (1985). Intermittent zones of rubble, rocks and barren sand with occasional sponges, hydroids, soft corals, hard corals, crinoids and gorgonians attached to rocky substrate are described. "Sea whip" type gorgonians (*Ellisella sp.*), often wrapped with basket stars, were noted common at one location off the south coast of Puerto Rico. Rugged rock habitat, described as large, closely-packed boulders with little or no sand, was noted to primarily occur in the Mona Passage. Most notably, an abundance of the potential structure-forming coral *M. myriaster* was reported at a depth of 197-212 m on the shelf margin south of the southwest corner of Puerto Rico.

Ongoing deep water research in the U.S. Caribbean includes the exploration and characterization of seafloor habitats, with ROVs, down to 1,000 meters within the U.S. Virgin Islands and Puerto Rico by NOAA (NOAA 2007). This effort aims to characterize and map moderate to deep water coral reef ecosystem habitats within targeted study areas. Priority areas include the deep waters of the Buck Island Reef National Monument, the Escollo Grappler seamount to the southeast of Puerto Rico and the La Parguera region along the southwestern coast of Puerto Rico.

Inspection of regional unpublished research reports and dredge station sorting sheets illuminate interesting possibilities for deep coral habitat. Selected citations from dredge reports (individual station records) and notes include the following:

> *For the U.S. Caribbean*: in Navassa Island waters two major structure forming corals (*M. oculata* and *E. rostrata*) were recovered, at 1,200 m, along with solitary corals (*Stephanocyathus laevifundus* and of the families *Deltocyathus* and *Desmophyllum*), gorgonians (of the genus *Acanella*, *Iridogorgia* and *Chrysogorigia*) and deep water fish (Staiger and Voss 1970).
>
> *For waters adjacent to the U.S. Caribbean*: in British Virgin Islands waters, at 205 - 380 m, one potential structure-forming coral species (*M. myriaster*) was recovered from the same location in a trawl net "festooned with stalked crinoids". Deep water fish and crustaceans were also recovered (Staiger 1969); in Saba waters, in 512 m off the northern edge of the Saba Bank, a large deep water gorgonian (*C. multiflora*) was recovered along with deep water fishes (Anon. 1956); south of Hispaniola in 135-169 m, the potential structure forming coral species (*M. myriaster*) was recovered along with numerous sponges, gorgonians and other invertebrates in a net noted as "We had to use the crane to lift it aboard…. The catch was very good". Deep water fish and crustaceans were also recovered. Similar "excellent" and "magnificent" catches were also noted from two nearby trawl sets that also recovered *M. myriaster* (Staiger and Voss 1970; Voss 1971).
>
> *For waters throughout the region*: in Venezuelan waters with *L. pertusa* at 406 m - "it was the best 10 ft. otter trawl tow I have seen in six years. There was a greater variety of organisms and a greater number than we usually get in a 41 ft. otter trawl tow" (Anon 1968); in the Straits of Florida, in waters just off just off Havana, Cuba, where *M. carolina*, *M. oculata*, and *M. myriaster* have been recovered - "the "pentacrinus grounds" [crinoid grounds] discovered by the *Blake* off Havana are world famous" (Voss 1966b); and in the Straits of Florida just southeast of the area of lithoherms on the Little Bahama Bank) with *L. pertusa*, *S. varibilis* and *E. profunda* at 738 m - "Tremendous amount of coral in net. Needed crane to lift it aboard. Good catch of fish and invertebrates" (Anon. 1973).

Though no direct information was found regarding the regional transport of deep coral larvae, the cosmopolitan distribution of shallow-water benthos of coral reefs as well as many deep water coral species (including the major structure-forming corals) indicates long term connectivity throughout the basin.

VI. SPECIES ASSOCIATIONS WITH DEEP CORAL COMMUNITIES

Fauna of deep-sea bio-buildups are among the least studied of marine assemblages. For example, the identification of deep-sea gorgonians, collected in the Caribbean and the Bahamas in the early 1960's, are, to date, being revised (e.g., Cairns 2007); deep-sea Gold corals collected on lithoherms in the Bahamas in the 1970's still await full identification (Messing pers. comm.), and crustaceans collected in the 1880's have long waited proper scientific descriptions (Larsen 1999).

Inspection of archival data and grey literature, including original station data sheets, cruise narratives and biological survey reports from 28 locations within the region identify a wide assortment of associated species occurring with the major structure-building deep-water corals; *E. profunda*, *L. pertusa*, *M. carolina*, *M. oculata* and *S. varibilis* (Appendix 8.2). Figure 8.21 illustrates several of these species in an idealized deep coral mound. Many of the reported associated species may grow to almost one meter in height (larger cnidarians and porifera).

Large deep sea sponges (phylum Porifera) are a potentially important megafauna component of deep sea coral habitats. Deep sea sponges have been recorded with structure-forming and potential habitat-forming corals (Appendix 8.2) and on deep water mounds, lithoherms and banks. It is unknown what habitat role they may play on deep water coral habitats. Colin (1978) reports that in some areas of shallow water reefs the biomass of sponges "can exceed that of any other group, including reef-building corals." Lang et al. (1975) reported that sponges (sclerosponges) can act as primary framework builders of reefs at depths of 70-105 m off Jamaica. Of primary interest are the larger calcareous sponges (class Calcarea), deep water glass sponges (class Hexatinellida), demosponges (class Demospongiae) and sclerosponges (class Sclerospongiae). Deep-sea sponges have been recorded up to 122 cm wide

Table 8.3. Potential fishing gear impacts on deep sea corals for the U.S. Caribbean.

	Measure of Impact					
Gear Type	**Current Fishery Use in Region**	**Potential Severity of Impact**	**Potential Extent of Impact from Fishing Gear**	**Current Geographic Extent of Use in Region**	**Overlap of use with coral habitat**	**Overall Rating of Gear Impact**
Bottom Trawl	None reported	High	High	NA	Uncertain	NA
Mid-water Trawl	None reported	Low	Low	NA	Uncertain	NA
Dredge	None reported	High	Low	NA	Uncertain	NA
Bottom-set Longline	to 109 m	Medium	Low	Unknown	Uncertain	Low
Bottom-set Gillnet	None reported	Medium	Medium	Unknown	Uncertain	Low
Longline traps or pots	to 183 m	High	Medium	To shelf edge	Uncertain	Low
Single pots	to 183 m	Low	Medium	To shelf edge	Uncertain	Low
Hook and line	to 600 m	Low	Low	Unknown	Uncertain	Low

at deep-sea coral depths in the Straits of Florida. Figure 8.12 illustrates a deep-sea sponge. Deep-sea sponges are subject of pharmacological investigations.

A number of fishes have been observed or collected in association with deep coral habitats. While most of these are demersal species (Appendix 8.2), certain commercially important pelagic species may also associate with deep-sea coral habitat. Swordfish (*Xiphias gladius*) have been encountered by submersibles visiting deep sea corals (*Lophelia*) in the Straits of Florida (Nizinski and Ross 2002) and in Bahamian deep waters at 600 m (Harbison and Janssen 1987). Larger deep coral mounds and lithoherms may play similar roles to seamounts, which are thought to attract pelagic fish because of an "enhanced primary productivity due to particular oceanographic conditions supporting a rich ecosystem" (Allain et al. 2006). In effect, seamounts influence oceanic currents in a way that promotes plankton to develop, acting as a feeding source for resident fish, attracting larger pelagic predators. These pelagic species are thought to use the seamounts unique underwater features primarily for food but also potentially as spawning grounds and/or nursery areas.

VII. STRESSORS ON DEEP CORAL COMMUNITIES

Serious potential threats to deep water coral communities found in other U.S. waters are not currently found in the U.S. Caribbean. No current examples were found of significant threats to deep water corals from the following: harvesting of precious coral, cable laying, oil and gas exploration, sedimentation, invasive species and destructive fishing practices (such as bottom trawling).

Fishing occurs to deep coral depths (>100 m) in the U.S. Caribbean and throughout the region. This activity is mainly focused on deep water snapper and grouper and includes commercial and recreational fishing effort. An extensive deep water fishery, primarily for snappers, occurs around Puerto Rico (Appeldoorn pers. comm.). Target species include black snapper (*Lutjanus griseus*), blackfin snapper (*L. buccanella*), vermilion snapper (*Rhomboplites aurorubens*) and silk snapper (*L. vivanus*) (FAO 1993; Kojis 2004; Cummings and Matos-Caraballo 2003).

Gear utilized in commercial deep water snapper and grouper fishing in the U.S. Caribbean includes vertical set line, bottom longline, handlines, electric or hydraulic reels and traps (Kojis 2004; Tobias 2004). Similar effort is reported throughout the region (FAO 1993). Figure 8.25 illustrates a typical commercial fishing vessel capable of fishing offshore for deepwater snapper and grouper in the U.S. Virgin Islands. The maximum reported depth for line fishing is 366 m (Swingle et al. 1970). The maximum reported depth for trap fishing is 183 m (Sheridan et al. 2006). During submersible observations, Nelson and Appeldoorn (1985) encountered ghost fishing traps at a depth of 121 m off the west end of St. Croix and a discarded longline at 236 m off the harbor entrance to San Juan, Puerto Rico.

Recreational fishing for deep water species in the U.S. Caribbean and throughout the region is termed "deep drop" fishing (also referred to as cannonball fishing). Gear includes expensive electric reels and heavy sash weights (commonly weighing 5 to 10 lbs) which allow fishing to potentially >600 m (Sword Fishing Central 2006). The Melton International Tackle Catalog (2007) lists electric deep drop reels up to $4,500 in price. Reels "capable of landing fish as deep as 500 fathoms [914 m]" are advertised (Melton 2007, pg 95). Heavy weights are needed for optimal deep drop fishing performance; to take the line straight down to the sea floor and keep the tackle as close to the bottom as possible, in a process called "bouncing," where the weight bounces up off the sea floor and the whole rig remains under the boat (Brooks 2007). Non-conventional weights, fashioned from pipes or other containers filled with concrete are also used. Deep drop fishing has recently gained in popularity with sport fishers, the 3nd annual 'Lords of the Deep' Fishing Tournament was held in September 2007 in Nassau, Bahamas. Figure 26 illustrates electric fishing reels utilized in deep-drop fishing. Such gear is available in the U.S. Caribbean. A small level of effort of deep-drop fishing is reported from the U.S. Caribbean and throughout the Caribbean region.

The association between deep-sea fishing and deep-sea coral habitat is unknown. However, a review of web-based fishing forums reveals that recreational sport fishers may be aware of and fishing on such:

> "You want to look for mounds, ridges, humps, etc. The key is learning the currents and exact location of your drop especially in very deep water (1000-2000 ft) [305-610 m]. You will find that on one particular mound, the peaks will hold one type of fish and the base of that same mound will hold another. Some deep water mounds in the Bahamas go up to a couple of hundred ft. [61 m] from the base. The Pomfret is one of my deep water favorites. We catch this species on the peaks of mounds. If your drop is off the mounds peak, you will have a tough time catching them." (Offshore Fishing Forum 2006).

Figure 8.26. Typical electric reels used in deep drop fishing. This gear is marketed in the U.S. Caribbean.

Table 8.3 details potential fishing gear impacts on deep-sea corals for the U.S. Caribbean with deep drop fishing included under "hook and line".

When compared to potential threats deep coral habitats experience in other U.S. waters (chiefly destructive bottom trawling) this effort does not currently pose a significant threat to deep corals. However, the potential for damage to deep corals from such fishing gear is well documented, and may increase as the amount of fishing effort increases (Chuenpagdee et al. 2003). Traps and weighted lines can crush structure-forming corals and entangle or snare softer octocorals. The potential impacts of regional commercial and recreational deep-sea fishing warrants further investigation. Additionally, the impact that the removal of large deep water predators may have on deep coral ecosystems is unknown. However, it is well documented that the overfishing of these species can have negative effects on shallow reef health (Dulvy et al. 2004; Steneck and Sala 2005; Mumby et al. 2006).

Figure 8.25. Bandit rigged boat - a type of commercial fishing vessel used to fish offshore for deepwater snapper and grouper in the U.S. Virgin Islands and capable of fishing to depths where deep water coral reside. Photo credit: Kojis 2005.

Current efforts to manage fisheries the Caribbean waters are exacerbated by a regional 'lack of capacity' in fisheries management (Haughton et al. 2004). Traditional management strategies (such as catch and release) may not work for deep-water species, as fish brought up from deep-sea coral depths expire en-route. Additionally, remoteness of location may play an important role with regard the management of deep-sea coral habitats. For example, the major structure forming corals *M. oculata* and *E. rostrata* have been found in the waters surrounding Navassa Island (Figure 8.5), an extremely remote uninhabited U.S. territory and illegal fishing activities are reported from Navassa's waters (Miller 2003). However, the closest inhabited United States territory, Guantanamo Bay Naval Base (Cuba), is located approximately 170 km distant.

Throughout the region, future fishing activities pose a significant potential threat, as shallow water fisheries resources are depleted and commercial and recreational effort moves into deeper water (Prado and Drew 1999; FAO 2000; Koslow et al. 2000; Roberts 2002). Inspection of research station sorting sheets and current literature reveal numerous fish species associated with deep corals that belong to taxa currently harvested in other regions and may be harvested in the Caribbean in the future. Fishes include targeted and by-catch deep-sea species such as deep-sea codfish, rattails or grenadiers, hake, dory, sea robins, wreakfish (*Polyprion americanus*) and sharks (Merrett and Haedrich 1997; Carpenter 2002; Freiwald 2004; Gordon 2004) (locations of these sites are illustrated in Figure 8.3, species are listed in Appendix 8.2). Wreakfish (Sedberry et al. 1994) and dogfish sharks are currently harvested in U.S. continental waters. Wreckfish and have been observed on deep coral habitat (mounds and lithoherms) in the Straits of Florida (Messing et al. 1990). Dogfish sharks are reported on deep coral mounds and lithoherms (Nizinski and Ross 2002) and associated with occurrences of structure-forming corals throughout the region (Appendix 8.2).

No significant threat of deep water trawling was found for the wider Caribbean. However, deep water shrimp trawlers are currently exploring fishing beyond 70 m in depth off Colombia (Gracia pers. comm.) and Reyes et al. (2005) note the need to asses the impacts of trawl fishing on the deep water coral banks off Colombia.

Oil and gas exploration does currently occur in the to U.S. Caribbean. However, this activity occurs in the southeast Caribbean, notably off Trinidad and Tobago, and in Straits of Florida waters off northwest Cuba. It is unknown what effect these activities have on deep coral communities. It is also unknown to what extent regional underwater cables and lines affect deep coral communities.

The harvest of precious corals, red and black corals, is prohibited in the U.S. Caribbean and there are no reports of current harvest activities. However, black coral jewelry, reportedly manufactured from corals harvested in the Cayman Islands, is available for purchase in the U.S. Virgin islands (Greenberg and Greenberg 2006; Bernard K. Passman Gallery, St. Thomas, pers. comm.). Black coral sold in the U.S. Caribbean is reportedly harvested in the western Caribbean from coral beds located at depths of 61-122 m (200-400 ft) (Bernard K. Passman Gallery, St. Thomas, pers. comm.). Regional countries listed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) trade database as exporting black coral (*Antipatharia* spp.) since 2001 include the Bahamas, British Virgin Islands, Cayman Islands, Cuba, Colombia, Dominican Republic, Mexico, Panama, and Trinidad and Tobago (Figure 8.4, some locations may be transshipment points) (CITES 2007). The basil axis of black coral is used in the manufacture of jewelry (Opresko and Sanchez 2005).

VIII. CURRENT CONSERVATION AND MANAGEMENT ACTIVITIES

In the U.S. Caribbean deep-water corals and other marine resources are under the jurisdiction of territory (USVI: 0-3 nmi from shore), commonwealth (Puerto Rico: 0-12 nmi from shore) and federal management authorities (U.S. EEZ and the waters around Navassa Island). Fisheries in the U.S. EEZ around USVI and Puerto Rico are managed under fishery management plans developed by the Caribbean Fishery Management Council (CFMC), based in Puerto Rico. Deep sea coral language in the recently reauthorized Magnuson-Stevens Act includes an affirmation of the Council's authority designate zones to protect deep sea corals from physical damage from fishing gear as part of their fishery management plans, without having to prove that corals constitute essential fish habitat [as amended by the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (Public Law 109-479), see Chapter 1]. Navassa Island is managed by the U.S. Fish and Wildlife Service as a National Wildlife Refuge that includes a 12 mile radius of marine habitats around the island. Commonwealth and territorial management authorities include the Puerto Rico Department of Natural and Environmental Resources and the United States Virgin Islands Department of Planning and Natural Resources.

Current efforts to manage fisheries in Caribbean waters are focused on shallow-water coral reef areas and associated fisheries (conch, grouper, Caribbean spiny lobster, etc.) (Sala et al. 2001; Theile 2001; FAO 2003). However, the Territory of the U.S. Virgin Islands includes antipatharians (black corals) in its local Endangered Species Act (ESA), thus granting the authority to protect black corals (no matter the depth) within USVI territorial waters. Puerto Rico implements the Federal Endangered Species Act (Federal ESA) in local waters. However, currently, no deep coral species are listed under the Federal ESA. The Caribbean Council manages corals under the Corals and Reef Associated Invertebrates of Puerto Rico and the U.S. Virgin Islands Fishery Management Plan (Coral FMP) (Caribbean Fishery Management Council 1994). It lists many coral genera and species that are found in both shallow and deep waters. Those species found in deep water (including *Iciligorgia schrammi* (deep sea fan), *Telesto* spp., *Ellisella* spp. (sea whips) and antipatharians (black corals) would be protected under the Coral FMP. There are no conservation or management efforts specifically targeting deep-water corals for the U.S. Caribbean or the wider Caribbean region.

An assessment of regional deep-sea recreational and commercial fishing effort, especially deep drop fishing, would provide managers with information concerning the potential impact of this activity has on deep-sea corals. The collection of socioeconomic information and perceptions and attitudes to policy options, along with standard fisheries information (such as fishing effort, frequency of activity, landing and bycatch information, etc.), could help minimize any negative impacts of policies directed at the conservation of deep sea coral ecosystems

IX. REGIONAL PRIORITIES TO UNDERSTAND AND CONSERVE DEEP CORAL COMMUNITIES

Morgan et al. (2006) advocate that ecosystem-based management, research and mapping and a ban on destructive fishing practices in deep sea coral areas are necessary to provide sufficient protection for deep-sea coral ecosystems.

Ongoing projects that may generate information regarding the distribution deep coral communities include the previously mentioned benthic habitat characterization effort by NOAA (NOAA 2007) and a coral reef assessment and habitat mapping effort of Navassa Island National Wildlife Refuge by NOAA and the National Park Service (Miller pers. comm.). The Navassa Island effort, although currently focused on shallow water reefs, could include deep-water investigations. Currently, no activities in the U.S. Caribbean are focused on the biology and ecology of deep coral communities.

Mapping the locations of deep coral habitat would be a valuable component of any true ecosystem based management program for the U.S. Caribbean. Mapping the locations of coral habitats gives a crucial spatial framework for managers to better understand the effects of ocean uses on the environment. Figure 8.5 illustrates existing managed areas in the U.S. Caribbean and surrounding waters that have potential deep water coral habitat (waters >100 m). Navassa Island Wildlife Refuge is the only managed area that includes documented deep water structure-forming and potential habitat-forming scleractinian corals (*E. rostrata*, *M. oculata* and *M. myriaster*).

Examples of archival data awaiting further inspection include the following: video footage and photographs recorded during the submersible observations around Puerto Rico and the U.S. Virgin Islands reported by Nelson and Appeldoorn (1985), stored at the National Marine Fisheries Service (NMFS) Southeast Fisheries Science Center in Pascagoula, Florida (Appeldoorn pers. comm.); video footage and dive records recorded during submersible observations at Navassa Island by the Center for Marine Conservation (now The Ocean Conservancy); station records from numerous research cruises kept on microfilm at the NMFS South East Fisheries Science Center in Miami, Florida; and cruise reports and other information kept at the academic institutions that carried out much original deep sea research - the University of Miami's Marine Invertebrate Museum in Miami, Florida, is one such location.

An assessment of regional deep-sea recreational and commercial fishing effort, especially deep drop fishing, would provide managers with information concerning the potential impact of this activity. The collection of socioeconomic information and perceptions and attitudes to policy options, along with standard fisheries information (such as fishing effort, frequency of activity, landing and bycatch information, etc.), could help minimize any negative impacts of policies directed at the conservation of deep sea coral ecosystems.

X. CONCLUSIONS

It is clear from this review that the U.S. Caribbean and the wider Caribbean region contain a huge diversity of deep water corals. However, information on regional distribution of deep corals is limited and needs great expansion if deep corals can be part of any meaningful ecosystem based management strategy. Nevertheless, the thorough description of deep coral mounds and lithoherms in the Bahamas and in the Straits of Florida and deep coral habitat off Colombia provides valuable information on the bathymetric and hydrographic conditions favoring the development of deep coral communities. From this information inferences may be made regarding the morphology, composition and organism zonation of regional deep coral communities and the potential for deep coral habitat in the U.S. Caribbean.

The lithoherms of the Straits of Florida are remarkable examples of the interaction of strong currents with a varied suite of benthos (corals, zoanthids, crinoids, alcyonarians, etc.) a rain of pelagic sediments and syndepositional cementation of the sediments and skeletal debris. This interaction produces current-resistant structures with a continual supply of new hard substrate for an attached and boring benthic community. It is these same interrelated processes that allow the development of ocean facing, wave-resistant shallow reefs. There are strong indications that the Straits of Florida contain undiscovered large areas of deep coral mounds and/or lithoherms and banks. Similarly, it seems likely that other areas throughout the Caribbean, including United States territories, with stronger currents may also have deep coral ecosystems. The possibility that deep-sea coral habitat in these areas harbor fish, which are exploitable (Appendix 8.2 and 8.3), deserves further attention.

Technical note

All images by Steven J. Lutz unless otherwise noted. Images may be modified for clarification.

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Appendix 8.1. Deep-sea corals of the wider Caribbean region, including those located in the U.S. Caribbean
▲ Bold denotes major and potential structure-forming scleractinia (species associated with deep water banks, lithoherms, etc.) and potential habitat-forming antipatharia, octocorallia, pennatulacea, and hydrozoa (species greater than or equal to 25 cm species greater than or equal to 25 cm in height or width
♠ Bold denotes distribution including U.S. Caribbean territories
‡ For material examined: HBOI = Harbor Branch Oceanographic Institute; USNM = United States National Museum

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
Phylum Cnidaria					
Class Anthozoa					
Subclass Hexacorallia (Zoantharia)					
Order Scleractinia					
	Caryophyllidae	*Anomocora fecunda*	Widespread Caribbean and Bahamas, including the **U.S. Virgin Islands**	37-640	Cairns 1979, 2000, UNEP-WCMC 2003; Reyes et al. 2005
	Caryophyllidae	*Anomocora marchadi*	Straits of Florida, southern Caribbean	35-229	Cairns 1979, 2000; Cairns and Zibrowis 1997
	Caryophyllidae	*Anomocora prolifera*	Straits of Florida, southern Caribbean, Lesser Antilles	30-329	Cairns 1979, 2000; Reyes et al. 2005
	Anthemiphylliidae	*Anthemiphyllia patera*	Straits of Florida, Bahamas, Lesser Antilles	500-700	Cairns 1979
	Rhizangiidae	*Astrangia poculata*	Throughout Caribbean, including **Puerto Rico**	0-263	Cairns 1999, 2000
	Dendrophylliidae	*Balanophyllia bayeri*	Mexico, Colombia	274-311	Cairns 1979; Reyes et al. 2005
	Dendrophylliidae	*Balanophyllia cyathoides*	Straits of Florida, Yucatan Channel, Lesser Antilles; Venezuela	45-494	Cairns 1979, 2000; Reyes et al. 2005
	Dendrophylliidae	*Balanophyllia dineta*	Southeastern Caribbean, Lesser Antilles	27-274	Cairns 2000
	Dendrophylliidae	*Balanophyllia floridana*	Straits of Florida, southeastern and western Caribbean	13-220	Cairns 2000
	Dendrophylliidae	*Balanophyllia hadros*	Only off Nicaragua	238-274	Cairns 1979
	Dendrophylliidae	*Balanophyllia palifera*	Bahamas, Antilles, Yucatan Channel, Colombia	53-708	Cairns 1979, 2000; Reyes et al. 2005

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
	Dendrophylliidae	*Balanophyllia wellsi*	Bahamas, Cuba, Grenada, Jamaica, Colombia	412-505	Cairns 1979, UNEP-WCMC 2003; Reyes et al. 2005
	Dendrophylliidae	*Bathypsammia fallosocialis*	Straits of Florida, St. Lucia	244-805	Cairns 1979
	Caryophyllidae	*Caryophyllia ambrosia caribbeana*	Widespread Caribbean, Bahamas, including **U.S. territories**	183-1646	Cairns 1979; Reyes et al. 2005
	Caryophyllidae	*Caryophyllia antillarum*	Straits of Florida, Bahamas, Antilles, including **US territories**	150-730	Cairns 1979, 2000
	Caryophyllidae	*Caryophyllia barbadendis*	Barbados; Colombia	129-249	Cairns 1979, 2000; Reyes et al. 2005
	Caryophyllidae	*Caryophyllia berteriana*	Widespread Caribbean, Bahamas, including **U.S. territories**	99-1033	Cairns 1979, 2000; Reyes et al. 2005
	Caryophyllidae	*Caryophyllia corrugata*	Antilles, Virgin Islands to Cuba, including **U.S. territories**	183-380	Cairns 1979
	Caryophyllidae	*Caryophyllia crypta*	Bahamas and Caribbean, Greater Antilles, southern and western Caribbean, including **U.S. territories**	12-183	Cairns 2000
	Caryophyllidae	*Caryophyllia parvula*	Antilles, Venezuela	97-399	Cairns 1979
	Caryophyllidae	*Caryophyllia paucipalata*	Lesser Antilles, including **U.S. territories**	714-843	Cairns 1979
	Caryophyllidae	*Caryophyllia polygona*	Straits of Florida, Antilles	700-1817	Cairns 1979
	Caryophyllidae	*Caryophyllia zopyros*	Antilles	73-618	Cairns 1979, 2000
	Caryophyllidae	*Cladocora debilis*	Straits of Florida, eastern and southern Caribbean, including **Puerto Rico**	32-480 (common 50-100)	Cairns 2000; UNEP-WCMC 2003; Reyes et al. 2005
	Dendrophylliidae	*Cladopsammia manuelensis*	Straits of Florida, St. Lucia	70-366	Cairns 1979, 2000
	Caryophyllidae	*Coenocyathus caribbeana*	Bahamas and Caribbean	5-100	Cairns 2000

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
	Caryophyllidae	*Coenocyathus parvulus*	Bahamas and Caribbean, including **U.S. territories**	97-399	Cairns 1979, 2000; Reyes et al. 2005
	Caryophyllidae	*Coenosmilia arbuscula*	Widespread Caribbean, Bahamas, including **U.S. territories**	74-622	Cairns 1979, 2000; Reyes et al. 2005
	Caryophyllidae	*Colangia immersa*	Throughout Caribbean, Bahamas, including **U.S. territories**	0.5-347	Cairns 2000
	Caryophyllidae	*Concentrotheca laevigata*	Straits of Florida, Yucatan Channel	183-800	Cairns 1979
	Turbinoliidae	*Cylicia inflata*	Only off Havana, Cuba	183-443	Cairns 1979
	Caryophyllidae	*Dasmosmilia lymani*	Straits of Florida, Cuba, Grenada, Venezuela	37-366	Cairns 1979, 2000, UNEP-WCMC 2003
	Caryophyllidae	*Dasmosmilia variegata*	Straits of Florida, southern Lesser Antilles	110-421	Cairns 1979, 2000
	Turbinoliidae	*Deltocyathoides stimpsonii*	Straits of Florida, Lesser Antilles	110-553	Cairns 1979, 2000
	Caryophyllidae	*Deltocyathus agassizii*	Straits of Florida, Anguilla	494-907	Cairns 1979
	Caryophyllidae	*Deltocyathus calcar*	Widespread Caribbean, Bahamas, including **U.S. territories**	81-675	Cairns 1979, 2000; Reyes et al. 2005
	Caryophyllidae	*Deltocyathus eccentricus*	Widespread Caribbean, Bahamas, including **U.S. territories**	183-907	Cairns 1979
	Caryophyllidae	*Deltocyathus italicus*	Widespread Caribbean, Bahamas, including **U.S. territories**	403-2634	Cairns 1979
	Caryophyllidae	*Deltocyathus moseleyi*	Straits of Florida, Belize, Lesser Antilles	201-777	Cairns 1979
	Caryophyllidae	*Deltocyathus pourtalesi*	Straits of Florida, Bahamas	311-567	Cairns 1979
	Dendrophylliaidae	***Dendrophyllia alternata***	Antilles, Bahamas	276-900	Cairns 1979
	Caryophyllidae	***Desmophyllum dianthus*** (=*D. cristagalli*)	Straits of Florida, Bahamas, Martinique, **U.S. Virgin Islands**	155-2200	Cairns 1979, 2000, UNEP-WCMC 2003
	Caryophyllidae	*Desmophyllum striatum*	Greater Antilles, Bahamas, including **U.S. territories**	277-823	Cairns 1979, 2000
	Dendrophylliaidae	*Eguchipsammia cornucopia*	Bahamas, Straits of Florida, Yucatan Channel, southeastern Caribbean	93-300	Cairns 1979, 2000; Reyes et al. 2005
	Dendrophylliaidae	*Eguchipsammia gaditana*	Yucatan Channel, Venezuela	97-505	Cairns 1979, 2000

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
	Dendrophylliaidae	***Enallopsammia profunda***	Straits of Florida, St. Lucia	403-1748	Cairns 1979
	Dendrophylliaidae	***Enallopsammia rostrata***	Straits of Florida, Bahamas, Antilles, western Caribbean, Antilles, including **U.S. Virgin Islands**	300-1646	Cairns 1979, UNEP-WCMC 2003
	Flabellidae	*Flabellum (pavoninum) atlanticum*	Bahamas, Cuba	357-618	Cairns 1979, UNEP-WCMC 2003
	Flabellidae	*Flabellum floridanum*	Western Straits of Florida, Mexico, Panama	80-366	Cairns 1979, 2000; UNEP-WCMC 2003
	Flabellidae	*Flabellum moseleyi*	Widespread Caribbean, including **U.S. territories**	216-1097	Cairns 1979
	Fungiacyathidae	*Fungiacyathus marenzelleri*	Bahamian archipelago	1450-2745	Cairns 1979
	Fungiacyathidae	*Fungiacyathus pusillus*	Straits of Florida, Yucatan, Lesser Antilles	285-439	Cairns 1979
	Fungiacyathidae	*Fungiacyathus symmetricus*	Widespread Caribbean, Bahamas.	183-1664	Cairns 1979
	Gardineriidae	*Gardineria minor*	Throughout Caribbean, Bahamas	2-146	Cairns 1979, 2000
	Gardineriidae	*Gardineria paradoxa*	Antilles, Yucatan Channel, Straits of Florida	97-700	Cairns 1979, 2000
	Gardineriidae	*Gardineria simplex*	Bahamas, Antilles, Yucatan Channel	46-241	Cairns 2000
	Guyniidae	*Guynia annulata*	Bahamas, Straits of Florida, western Caribbean, Antilles	30-653	Cairns 1979, 2000
	Flabellidae	*Javania cailleti*	Widespread Caribbean, Bahamas, including U.S. territories	30-1809	Cairns 1979, 2000; Reyes et al. 2005
	Flabellidae	*Javania pseudoalabastra*	Bahamas, Jamaica	1089-1234	Cairns 1979
	Caryophyllidae	*Labyrinthocyathus langae*	Straits of Florida, Bahamas, Antilles, western Caribbean	695-810	Cairns 1979
	Micrabaciidae	*Leptopenus discus*	Only off south east Cuba	2842-3475	Cairns 1979
	Caryophyllidae	***Lophelia pertusa***	Straits of Florida, Bahamas, southern Caribbean, Antilles, including **Puerto Rico and U.S. Virgin Islands**	146-1200	Cairns 1979, 2000, UNEP-WCMC 2003
	Pocilloporidae	*Madracis asperula*	Widespread Caribbean, including **U.S. territories** (absent Bahamas)	24-311	Cairns 2000; Reyes et al. 2005
	Pocilloporidae	*Madracis brueggemanni*	Southern Caribbean	51-130	Cairns 2000

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	Pocilloporidae	***Madracis myriaster***	Widespread Caribbean, Bahamas, including **Puerto Rico and U.S. Virgin Islands**	20-1220	Cairns 1979, 2000, UNEP-WCMC 2003
	Pocilloporidae	*Madracis* pharensis forma *pharensis*	Widespread Caribbean, Bahamas, including U.S. territories	11-333	Cairns 2000; Reyes et al. 2005
	Oculinidae	***Madrepora carolina***	Greater Antilles, Bahamas, Tobago, western Caribbean, including **Puerto Rico and U.S. Virgin Islands**, Venezuela	53-801 (common 100-300)	Cairns 1979, 2000; UNEP-WCMC 2003; Reyes et al. 2005
	Oculinidae	***Madrepora oculata***	Widespread Caribbean, Bahamas, including **Puerto Rico and U.S. Virgin Islands**	144-1391	Cairns 1979
	Oculinidae	*Oculina tenella*	Straits of Florida, Cuba	25-159 (common 40-60)	Cairns 2000; UNEP-WCMC 2003
	Caryophyllidae	*Oxysmilia rotundifolia*	Widespread Caribbean, Bahamas, including **U.S. territories**	46-640	Cairns 1979, 2000; Reyes et al. 2005
	Caryophyllidae	*Paracyathus pulchellus*	Widespread Caribbean, including **U.S. territories**	17-250	Cairns 1979, 2000; Reyes et al. 2005
	Turbinoliidae	*Peponocyathus folloculus*	Straits of Florida, Antilles	284-457	Cairns 1979
	Caryophyllidae	*Phacelocyathus flos*	Bahamas, Antilles, western Caribbean	20-355	Cairns 1979, 2000
	Flabellidae	*Placotrochides frusta*	Lesser Antilles	497-907	Cairns 1979
	Caryophyllidae	*Polycyathus mayae*	Straits of Florida, Bahamas, northern Caribbean, including **U.S. territories**, Barbados	137-309	Cairns 2000; Reyes et al. 2005
	Caryophyllidae	*Polycyathus senegalensis*	Disjunct distribution, Florida, southern Caribbean	12-143	Cairns 2000
	Flabellidae	*Polymyces fragilis*	Straits of Florida, Bahamas, western and southern Caribbean, southern Lesser Antilles	75-822	Cairns 1979, 2000; Reyes et al. 2005
	Guyniidae	*Pourtalocyathus hispidus*	Straits of Florida, Bahamas, Antilles, including **U.S. territories**	349-1200	Cairns 1979
	Caryophyllidae	*Premocyathus cornuformis*	Straits of Florida, Bahamas, northern and eastern Caribbean	137-931	Cairns 1979, 2000

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	Dendrophylliaidae	*Rhizopsammia goesi*	Lesser Antilles, Colombia, Bahamas, including **U.S. Virgin Islands**	4.5-119	Cairns 1977, 2000, UNEP-WCMC 2003
	Caryophyllidae	*Rhizosmilia gerdae*	Straits of Florida, Bahamas, Yucatan Channel, northeastern Antilles, including **U.S. territories**	123-549	Cairns 1979, 2000
	Caryophyllidae	*Rhizosmilia maculata*	Widespread Caribbean, Bahamas, including **U.S. territories**	0.5-508	Cairns 2000
	Guyniidae	*Schizocyathus fissilis*	Straits of Florida, Bahamas, western Caribbean, Antilles (from **Puerto Rico** to Grenada)	88-640	Cairns 1979, 2000
	Caryophyllidae	***Solenosmilia variabilis***	Straits of Florida, Lesser Antilles, Jamaica, southern Caribbean	220-1383	Cairns 1979
	Guyniidae	*Stenocyathus vermiformis*	Straits of Florida, western Caribbean, Bahamas, Antilles, including **U.S. territories**	165-835	Cairns 1979, 2000
	Caryophyllidae	*Stephanocyathus coronatus*	Throughout Caribbean, Bahamas, including **U.S. territories**	543-1250	Cairns 1979
	Caryophyllidae	*Stephanocyathus diadema*	Widespread Caribbean, including **U.S. territories**	795-2113	Cairns 1979
	Caryophyllidae	*Stephanocyathus laevifundus*	Antilles, Panama, Straits of Florida, and off **Navassa Island**	300-1158	Cairns 1979
	Caryophyllidae	*Stephanocyathus paliferus*	Widespread Caribbean, Bahamas	299-715	Cairns 1979
	Caryophyllidae	*Tethocyathus cylindraceus*	Straits of Florida, Jamaica, Bahamas, Barbados.	155-649	Cairns 1979
	Caryophyllidae	*Tethocyathus recurvatus*	Yucatan Channel	320-488	Cairns 1979
	Caryophyllidae	*Tethocyathus variabilis*	Straits of Florida, Yucatan, Jamaica, including **U.S. territories**	320-488	Cairns 1979
	Caryophyllidae	*Thalamophyllia gombergi*	Only from Pourtales Terrace, Florida	155-220	Cairns 1979
	Caryophyllidae	*Thalamophyllia riisei*	Bahamas, Antilles, including **U.S. territories, Colombia**	4-914	Cairns 1979, 2000; Reyes et al. 2005
	Dendrophylliidae	*Thecopsammia socialis*	Gerogia to FL Keys, Bahamas	214-878	Cairns 1979; UNEP-WCMC 2003
	Turbinoliidae	*Trematotrochus corbicula*	Only northwest Cuba	400-576	Cairns 1979

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
	Caryophyllidae	*Trochocyathus fossulus*	Bahamas, Virgin Islands, including **U.S. territories**	205-380	Cairns 1979
	Caryophyllidae	*Trochocyathus rawsonii*	Widespread Caribbean, Bahamas, including **U.S. territories**	55-700	Cairns 1979, 2000
	Dendrophylliaidae	*Trochopsammia infundibulum*	northwestern Cuba, Lesser Antilles	532-1372	Cairns 1979
Order Zoanthidea					
	Gerardiidae	*Gerardia sp.*	Bahamas (Straits of Florida)	>100 (~580-630)	Messing et al. 1990
Order Antipatharia					
	Aphanipathidae	*Acanthopathes humilis*	Bahamas, Barbados, Cuba, Grenada, Mexico, Montserrat, Saint Vincent and the Grenadines	129 - 491	Opresko 1972; UNEP-WCMC 2003; Opresko 2006
	Aphanipathidae	*Acanthopathes thyoides*	Cuba, Saint Vincent and the Grenadines	~40-240	Opresko 1972; UNEP-WCMC 2003; Opresko 2006
	Antipathidae	***Allopathes desbonni***	Barbados, Cuba, Guadeloupe, Montserrat	129-161	Opresko and Cairns 1994; UNEP-WCMC 2003; Opresko 2006
	Antipathidae	***Antipathes americana?***	**U.S. Virgin Islands**, Grenada, Netherlands Antilles	37-532	Brook 1889; Opresko 1972; Warner 1981; OBIS 2006
	Antipathidae	***Antipathes atlantica***	Colombia, Jamaica, Mexico, Trinidad and Tobago	10 - 115	Warner 1981; UNEP-WCMC 2003; Reyes et al. 2005; Opresko 2006
	Antipathidae	***Antipathes caribbeana***	Bahamas, Colombia, **Puerto Rico**, Greater and Lesser Antilles	11->100 (common 30-60)	Opresko 1996; UNEP-WCMC 2003; Opresko and Sanchez 2005
	Antipathidae	*Antipathes columnaris*	Greater and Lesser Antilles, including **U.S. Virgin Islands**, Venezuela	73 - 567	Opresko 1974; UNEP-WCMC 2003; Reyes et al. 2005; Opresko 2006
	Antipathidae	*Antipathes lenta*	Straits of Florida, Cuba, Saint Vincent and the Grenadines, Trinidad and Tobago, Barbados, Honduras, Panama, Colombia, Venezuela	50-200	Opresko 1972; UNEP-WCMC 2003; Opresko and Sanchez 2005; Reyes et al. 2005; OBIS 2006; Opresko 2006

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
	Antipathidae	***Antipathes gracilis***	from Colombia north throughout the Caribbean, including Panama, Trinidad and Tobago, and Colombia	20-160	Brook 1889, Warner 1981, STRI 2006; Reyes et al. 2005
	Antipathidae	*Antipathes rhipidion?*	**U.S. Virgin Islands**	Unk	UNEP-WCMC 2003
	Antipathidae	*Antipathes tristis?*	Barbados, Guadeloupe, Martinique, Montserrat, Saint Lucia	Unk	UNEP-WCMC 2003
	Aphanipathidae	*Aphanipathes pedata*	Widespread Caribbean	~60-310	Opresko 1974; Opresko 2006
	Aphanipathidae	*Aphanipathes salix*	Guadeloupe, Colombia	107-333	Opresko 1972; UNEP-WCMC 2003; Reyes et al. 2005; Opresko 2006
	Schizopathidae	*Bathypathes alternata*	Straits of Florida (Bahamas), Yucatan Channel	~100-5000	Brook 1889 ; Opresko 1974; Opresko 2002; Opresko 2006
	Schizopathidae	*Bathypathes patula*	Mexico, **Puerto Rico**, Saint Kitts and Nevis, Caribbean Sea Basin, Cayman Trench, Yucatan Basin	100-5000	Brook 1889; Opresko 1974; Keller, et al. 1975; Opresko 2002; UNEP-WCMC 2003; OBIS 2006; Opresko 2006
	Cladopathidae	*Chrysopathes sp.*	Widespread Caribbean	>100	Opresko 2006
	Antipathidae	*Cirrhipathes spiralis?*	Barbados, Cuba, Martinique, Montserrat, St. Vincent and the Grenadines		UNEP-WCMC 2003
	Aphanipathidae	*Distichopathes disticha*	Martinique, Mexico	95-190	Opresko 2004; CITES 2006; Opresko 2006
	Aphanipathidae	***Distichopathes filix***	Bahamas, Barbados, Cuba, Dominica, Guadeloupe, Martinique, Montserrat, Saint Vincent and the Grenadines	~175-450	Opresko 2006; Opresko 1972; UNEP-WCMC 2003
	Aphanipathidae	*Elatopathes abietina*	Bahamas, Barbados, Cuba, Martinique, Mexico, Nicaragua, Saint Vincent and the Grenadines; Colombia	31 - 310	Opresko 1972; Rezak et al. 1985; UNEP-WCMC 2003; Reyes et al. 2005; Opresko 2006
	Cladopathidae	*Heliopathes americana*	Widespread Caribbean	>100	Opresko 2003; Opresko 2006
	Leiopathidae	***Leiopathes glaberrima***	Straits of Florida, Jamaica, Mexico; Venezuela, Bahamas	176 - 549	Opresko 1974; UNEP-WCMC 2003; Opresko 2006; Material examined USNM 1026305

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
	Schizopathidae	***Parantipathes tetrasticha***	Cuba, Guyana, Mexico, **Puerto Rico**, Saint Lucia	175 - 428	Opresko 1972; Opresko 2002; UNEP-WCMC 2003; Opresko 2006
	Schizopathidae	*Phanopathes rigida*	Bahamas, Barbados, Colombia, Cuba, Guadeloupe, Venezuela	64 - 640	Opresko 1972; Opresko 2002; UNEP-WCMC 2003; Opresko 2006
	Myriopathidae	***Plumapathes pennacea***	Throughout Caribbean, including **U.S. Virgin Islands & Puerto Rico**	3-229	Opresko 1974; Colin 1978; UNEP-WCMC 2003, CITES 2006; Opresko 2006
	Antipathidae	*Stichopathes lutkeni*	Barbados, Colombia, Dominican Republic, Trinidad and Tobago	~14-115	Brook 1889; Humann 1993; UNEP-WCMC 2003; Reyes et al. 2005; Opresko 2006
	Antipathidae	*Stichopathes occidentalis*	Caribbean region	~20-160	Brook 1889; Opresko 2006; Reyes et al. 2005
	Antipathidae	*Stichopathes pourtalesi*	Barbados, Colombia, Cuba, Grenada, Martinique, Montserrat, Saint Vincent and the Grenadines	>100	Pourtalès 1874, 1880; Brook 1889; Reyes et al. 2005; CITES 2006; Opresko 2006
	Myriopathidae	***Tanacetipathes barbadensis***	Barbados, Trinidad and Tobago	~60-345	Brook 1889; van der Land and Opresko 2001; Warner 1981; UNEP-WCMC 2003; Opresko 2006
	Myriopathidae	***Tanacetipathes hirta***	Throughout Caribbean, including **Puerto Rico**	13 - 357	Opresko 1972; Colin 1978; Warner 1981; UNEP-WCMC 2003; Opresko 2006
	Myriopathidae	***Tanacetipathes tanacetum***	Throughout Caribbean, including Puerto Rico	46 - 915	UNEP-WCMC 2003; OBIS 2006; Opresko 2006
	Myriopathidae	***Tanacetipathes thamnea***	Trinidad and Tobago	~45-345	Opresko 1970; Warner 1981; UNEP-WCMC 2003; Opresko 2006
Subclass Octocorallia					
Order Alcyonacea					
	Alcyoniidae	*Alcyonium digitatum*	Western Atlantic	>200	Cairns 2005
	Alcyoniidae	*Anthomastus agassizi*	Straits of Florida, Bahamas	320-3186	Cairns 2005

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
	Alcyoniidae	*Anthomastus robusta* var. *delta*	Western Atlantic	>200	Cairns 2005
	Alcyoniidae	*Bellonella rubistella*	Throughout Caribbean	24-329	Cairns 2005
	Clavulariidae	*Carijora* (=*Telesto*?) *operculata*	Straits of Florida (off Havana, Cuba), probably throughout Antilles	60-298	Cairns 2005
	Nephtheidae	*Drifta glomerata*	Western Atlantic	>200	Cairns 2005
	Nephtheidae	*Duva florida*	Western Atlantic	>200	Cairns 2005
	Nephtheidae	*Gersemia rubiformia*	Western Atlantic	>200	Cairns 2005
	Nephtheidae	***Neospongodes portoricensis***	Bahamas, Caribbean	37-503	Humann 1993
	Nidaliiae	*Nidalia deichmannae*	Western Atlantic	>200	Cairns 2005
	Nidaliiae	*Nidalia dissidens*	Western Atlantic	>200	Cairns 2005; Reyes et al. 2005
	Nidaliiae	*Nidalia occidentalis*	Throughout Caribbean	37-311	Cairns 2005; Reyes et al. 2005
	Nidaliiae	*Nidalia rubrapunctata*	Western Atlantic	~82->200	Cairns 2005
	Nephtheidae	*Pseudodrifa capnella nigra*	Straits of Florida (off Havana, Cuba), Bahamas	60-878	South Atlantic Fishery Management Council 1998; Cairns 2005; Reed 2006
	Clavulariidae	*Scleranthelia rugosa rugosa*	Throughout Caribbean	175-586	Cairns 2005
	Nephtheidae	*Stereonepthya portoricensis*	Western Atlantic	>200	Cairns 2005
	Clavulariidae	*Stereotelesto* (=*Telesto*) *corallina*	Bahamas, Antilles, including **Puerto Rico**	23-188	Bayer 1961; Humann 1993
	Clavulariidae	*Telesto nelleae*	Straits of Florida (off Havana, Cuba), Bahamas	27-1153	Bayer 1961; South Atlantic Fishery Management Council 1998; Cairns 2005
	Clavulariidae	*Telesto septentrionalis*	Western Atlantic	>200	Cairns 2005
	Nephtheidae	*Trachythela rudis*	Western Atlantic	805	Cairns 2005
Order Gorgonacea					
	Isididae	*Acanella arbuscula*	Western Atlantic	>200	Cairns 2005
	Isididae	*Acanella eburnea*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Acanthactis austera*	Western Atlantic	>200	Cairns 2005

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	Plexauridae	*Acanthactis scabra*	Western Atlantic	>200	Cairns 2005
	Acanthogorgiidae	*Acanthogorgia armata*	Western Atlantic	>200	Cairns 2005
	Acanthogorgiidae	*Acanthogorgia aspera*	Throughout Caribbean, including **Puerto Rico**	>183	Watling and Auster 2005; Bayer 1961
	Acanthogorgiidae	*Acanthogorgia schrammi*	Straits of Florida; Guadeloupe; Colombia	>200	Veronique 1987; Watling and Auster 2005; Reyes et al. 2005
	Primnoidae	***Acanthoprimnoa goesi***	Straits of Florida, Bahamas, **Puerto Rico**, Virgin Islands, including **U.S. Virgin Islands**	137-595	Cairns and Bayer 2004b; Cairns 2005
	Primnoidae	*Acanthoprimnoa pectinata*	northeastern Yucatan, lesser Antilles, Straits of Florida	194-686	Cairns and Bayer 2004b; Cairns 2005
	Anthothelidae	*Anthothela bathybius*	Western Atlantic	>200	Cairns 2005
	Anthothelidae	*Anthothela grandiflora*	Western Atlantic	>200	Cairns 2005
	Anthothelidae	*Anthothela grandiflora sensu*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Bebryce cinerea*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Bebryce grandis*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Bebryce parastellata*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Caliacis nutans*	Western Atlantic	>200	Cairns 2005
	Primnoidae	***Callogorgia americana americana***	Straits of Florida, Lesser Antilles, including **U.S. territories**	183-732	Cairns & Bayer 2002; Cairns 2005
	Primnoidae	***Callogorgia gracilis***	Throughout Caribbean, Bahamas, Antilles	82-514	Cairns & Bayer 2002; Cairns 2005
	Primnoidae	*Callogorgia linguimaris*	Only Bahamas	1116	Cairns & Bayer 2002; Cairns 2005
	Primnoidae	***Calyptrophora antilla***	Windward Passage	1399	Bayer 2001; Cairns 2005
	Primnoidae	*Calyptrophora gerdae*	Straits of Florida	229-556	Bayer 2001; Cairns 2005
	Primnoidae	***Calyptrophora pillsburyae***	Lesser Antilles	686-1125	Bayer 2001; Cairns 2005
	Primnoidae	*Calyptrophora trilepis*	Straits of Florida, Bahamas	593-911	Bayer 2001; Cairns 2005
	Primnoidae	***Candidella imbricata***	Straits of Florida, Bahamas, Antilles	514-2063	Cairns and Bayer 2004b; Cairns 2005; Watling and Auster 2005; Cairns personal Comm.

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	Isididae	*Caribisis simplex*	Western Atlantic	>200	Cairns 2005
	Chrysogorgiidae	*Chalcogorgia pellucida*	Western Atlantic	>200	Cairns 2005
	Isididae	*Chelidonisis aurantiaca mexicana*	Western Atlantic	>200	Cairns 2005
	Chrysogorgiidae	*Chrysogorigia agassizii*	Western Atlantic	>200	Cairns 2005
	Chrysogorgiidae	*Chrysogorigia desbonni*	Greater and Lesser Antilles, Bahamas, Guadeloupe, Martinique, Colombia	155-595	Veronique 1987; Cairns 2001; Cairns 2005; Reyes et al. 2005
	Chrysogorgiidae	*Chrysogorigia elegans*	Southeastern Caribbean, Lesser Antilles, Martinique	128-1716	Cairns 2001; Cairns 2005
	Chrysogorgiidae	*Chrysogorigia fewkesii*	Antilles, Caribbean	403-1200	Cairns 2001; Cairns 2005
	Chrysogorgiidae	***Chrysogorigia multiflora***	Antilles, Bahamas, Straits of Florida	320-1354	Cairns 2001; Cairns 2005
	Chrysogorgiidae	***Chrysogorigia spiculosa***	Gulf of Mexico, Lesser Antilles	914-2256	Cairns 2001; Cairns 2005
	Chrysogorgiidae	*Chrysogorigia squamata*	Antilles, Yucatan	431-1046	Cairns 2001; Cairns 2005
	Chrysogorgiidae	*Chrysogorigia thrysiformis*	Greater and Lesser Antilles, Bahamas	146-526	Cairns 2001; Cairns 2005
	Coralliidae	*Corallium medea*	Straits of Florida	>200	Bayer 1961; Cairns 2005; Watling and Auster 2005
	Coralliidae	*Corallium niobe*	Straits of Florida	659-677	Bayer 1961; Cairns 2005; Watling and Auster 2005
	Ellisellidae	*Ctenocella* (*Ellisella*) *atlantica*	Western Atlantic	>200	Cairns 2005
	Primnoidae	*Dasystenella acanthina*	Western Atlantic	>200	Cairns 2005
	Dendrobrachiidae	*Dendrobrachia multispina*	Western Atlantic	>200	Cairns 2005
	Anthothelidae	***Diodogorgia nodulifera?***	Throughout Caribbean, including **Puerto Rico**, Bahamas, Guadeloupe	14-183	Veronique 1987; Bayer 1961; Humann 1993
	Chrysogorgiidae	*Distichogorgia sconsa*	Straits of Florida	>200	Cairns 2005; Watling and Auster 2005
	Plexauridae	*Echinomuricea atlantica*	Western Atlantic	>200	Cairns 2005
	Ellisellidae	***Ellisella barbadensis***	Striats of Florida, Antilles, including **U.S. Virgin Islands**	20-488	Bayer 1961; Veronique 1987; Humann 1993; Cairns 2005; Armstrong et al. 2006

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
	Ellisellidae	***Ellisella elongata***	Antilles, **Puerto Rico**, Bahamas, southeastern Caribbean	15-219	Humann 1993; Bayer 1961; Caribbean Fishery Management Council 2004; Cairns 2005
	Ellisellidae	*Ellisella funiculina*	Western Atlantic	>200	Cairns 2005
	Ellisellidae	*Ellisella grandiflora*	Guadeloupe	350	Veronique 1987; Cairns 2005
	Ellisellidae	*Ellisella grandis*	Western Atlantic	>200	Cairns 2005
	Ellisellidae	*Ellisella nivea*	Western Atlantic	92~>200	Cairns 2005
	Ellisellidae	*Ellisella rosea*	Western Atlantic	52~>200	Cairns 2005
	Ellisellidae	*Ellisella schmitti*	Western Atlantic	61~>200	Cairns 2005
	Gorgoniidae	*Eunicella albatrossae*	Western Atlantic	>200	Cairns 2005
	Gorgoniidae	***Eunicella modesta***	Straits of Florida, Bahamas	274-3236	Watling and Auster 2005; Reed 2006
	Gorgoniidae	*Eunicella tenuis*	Western Atlantic	>200	Cairns 2005
	Plexauridae	***Hypnogorgia pendula***	Guadeloupe, Martinique	176	Veronique 1987; Cairns 2005; Material examined HBOI 26-V-06-1-17 (Reed 2006)
	Anthothelidae	***Iciligorgia schrammi***	Straits of Florida, Antilles, southeastern Caribbean	11-366	Humann 1993; Cairns 1977; Cairns 2005
	Chrysogorgiidae	*Iridogorgia pourtalesi*	Guadeloupe	1343	Cairns 2005; Veronique 1987
	Isididae	*Isidella longiflora?*	Straits of Florida	to 667	Reed 2006
	Ellisellidae	*Junceella antillarum*	Western Atlantic	>200	Cairns 2005
	Isididae	***Keratoisis flexibilis***	Straits of Florida, Bahamas, Mexico, Guadeloupe, Colombia, Venezuela	170-878	Cairns 2005; Watling and Auster 2005
	Isididae	***Keratoisis ornata***	Straits of Florida, Bahamas, Cuba	274-3236	Bedford Institute of Oceanography 2003; Cairns 2005; Watling and Auster 2005
	Isididae	*Keratoisis siemensii*	Western Atlantic	>200	Cairns 2005
	Isididae	*Keratosis simplex*	Martinique	611	Cairns 2005; Veronique 1987
	Isididae	*Lepidisis caryophyllia*	Martinique, Guadeloupe	607-1067	Cairns 2005; Veronique 1987
	Isididae	*Lepidisis longiflora*	Straits of Florida, Caribbean	743-1125	Cairns 2005; Watling and Auster 2005

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
	Gorgoniidae	*Leptogorgia euryale?*	Southern Lesser Antilles	1060-3000	Bayer 1952; Keller et al. 1975
	Gorgoniidae	*Leptogorgia stheno?*	Southern Lesser Antilles	1060-3000	Bayer 1952; Keller et al. 1975
	Gorgoniidae	*Lophogorgia cardinalis*	Straits of Florida (Cuba)	26-123	Bayer 1961; South Atlantic Fishery Management Council 1998; Cairns 2005
	Chrysogorgiidae	*Metallogorgia splendens*	Western Atlantic	>200	Cairns 2005
	Plexauridae	***Muricea laxa***	Straits of Florida, Bahamas, Antilles	18-128	Bayer 1961; Cairns 1977; Humann 1993; Cairns 2005
	Plexauridae	*Muriceides* (=*Trachymuricea*) *hirta*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Muriceides kukenthali*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Muriceopsis petila*	Florida, Bahamas, Guadeloupe	67-455	Cairns 2005; Bayer 1961; Veronique 1987
	Primnoidae	***Narella bellissima***	Straits of Florida, Bahamas, Lesser Antilles, including **U.S. territories**	161-792	Cairns and Bayer 2003; Cairns 2005
	Primnoidae	***Narella pauciflora***	Straits of Florida, Antilles, **Puerto Rico**, Bahamas, Mexico	738-1473	Cairns and Bayer 2003; Cairns 2005
	Primnoidae	*Narella regularis*	Straits of Florida, Lesser Antilles and Bahama.	366-792	Veronique 1987; Cairns and Bayer 2003; Cairns 2005; Watling and Auster 2005
	Primnoidae	***Narella spectabilis***	Only Bahamas.	1485	Cairns and Bayer 2003; Cairns 2005
	Primnoidae	***Narella versluysi***	Straits of Florida, Cuba.	677-900	Cairns and Bayer 2003; Cairns 2005
	Ellisellidae	***Nicella goreaui***	Bahamas and southern Caribbean	45-146	Cairns 2007
	Ellisellidae	***Nicella americana***	Bahamas, Antilles, southern Caribbean	62-237	Cairns 2007
	Ellisellidae	***Nicella deichmannae***	Bahamas, northweatern Caribbean, Antilles, incluuding **U.S. territories**	27-403	Cairns 2007
	Ellisellidae	***Nicella hebes***	Western Atlantic, including Bahamas and southern coast of Caribbean to Nicaragua	27-327	Cairns 2005; Cairns 2007
	Ellisellidae	***Nicella lanceolata***	Only Grand Cayman Island	229-244	Cairns 2007

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
	Ellisellidae	***Nicella obesa***	Bahamas, Antilles from Cuba to Barbados, incluuding **U.S. territories**, Venezuela	174-819	Cairns 2007; Cairns 2005; Veronique 1987
	Ellisellidae	***Nicella guadelupensis***	Bahamas, Antilles, including **U.S. territories**, Venezuela	27-395	Cairns 2007
	Ellisellidae	*Nicella* sp. A.	Western Atlantic	55-329	Cairns 2007
	Ellisellidae	*Nicella gracilis*	Bahamas, Antilles, Venezuela	60-481	Cairns 2007
	Ellisellidae	***Nicella robusta***	Bahamas, Caribbean	110-259	Cairns 2007
	Primnoidae	***Paracalyptrophora carinata***	Only St. Lucia	514	Cairns and Bayer 2004a; Cairns 2005
	Primnoidae	***Paracalyptrophora duplex***	Straits of Florida, Cuba, Antilles, and Bahamas	374-555	Cairns and Bayer 2004a; Cairns 2005
	Primnoidae	***Paracalyptrophora simplex***	Straits of Florida, Bahamas, Yucatan	165-706	Cairns and Bayer 2004a; Cairns 2005
	Paragorgiidae	***Paragorgia*** (=*boschmai*) ***johnsoni***	Straits of Florida, Bahamas	522-608	Watling and Auster 2005; material examined USNM 35928; Cairns personal comm.
	Plexauridae	*Paramuricea echinata*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Paramuricea grandis*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Paramuricea multispina*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Paramuricea placomus*	Straits of Florida, Cuba (off Havana)	247-805	Cairns 2005
	Plexauridae	*Placogorgia mirabilis*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Placogorgia rudis*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Placogorgia tenius*	Western Atlantic	>200	Cairns 2005; Reyes et al. 2005
	Plexauridae	*Placogorgia tribuloidea*	Western Atlantic	>200	Cairns 2005
	Primnoidae	*Plumarella aculeata*	Bahanas and northern Straits of Florida	400-900	Cairns and Bayer 2004b; Cairns 2005
	Primnoidae	*Plumarella aurea*	Straits of Florida, Cuba	310-878	Cairns and Bayer 2004b; Cairns 2005
	Primnoidae	*Plumarella dichotoma*	Straits of Florida	494-1065	Cairns and Bayer 2004b; Cairns 2005

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
	Primnoidae	*Plumarella pellucida*	Straits of Florida, Bahamas	549-1160	Cairns and Bayer 2004b; Cairns 2005
	Primnoidae	***Plumarella pourtalesii* typical**	Straits of Florida, Cuba	196-882	Cairns and Bayer 2004b; Cairns 2005
	Primnoidae	***Plumarella pourtalesii var. obtusa***	Straits of Florida	183-743	Cairns and Bayer 2004b; Cairns 2005; Cairns personal comm.
	Primnoidae	***Plumarella pourtalesii* var. *robusta***	Straits of Florida	183-850	Cairns and Bayer 2004b; Cairns 2005
	Primnoidae	***Primnoa resedaeformis***	Western Atlantic	>200	Cairns 2005
	Primnoidae	*Primnoella delicatissima*	Western Atlantic	>200	Cairns 2005
	Primnoidae	*Primnoella divaricata*	Western Atlantic	>200	Cairns 2005
	Primnoidae	*Primnoella polita*	Western Atlantic	>200	Cairns 2005
	Isididae	*Primnosis rigida*	Western Atlantic	>200	Cairns 2005
	Plexauridae	***Pseudoplexaura porosa?***	Straits of Florida, Antilles, southeastern Caribbean	3-283	Cairns 1977; Kapela and Lasker 1999
	Chrysogorgiidae	***Radicipes gracilis***	Straits of Florida, southern Lesser Antilles	>200	Keller, et al. 1975; Bedford Institute of Oceanography 2003; Watling and Auster 2005; Cairns 2005
	Ellisellidae	***Riisea paniculata***	Bahamas, Caribbean, including **U.S. territories**	110-704	Cairns 2007
	Plexauridae	*Scleracis guadelupensis*	Guadeloupe, Martinique	176-350	Veronique 1987; Cairns 2005
	Plexauridae	*Scleracis petrosa*	Guadeloupe, Martinique	275-1607	Veronique 1987; Cairns 2005
	Isididae	*Stenisis humilis*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Swiftia casta*	Straits of Florida, Cuba (off Havana), Yucatan Channel	40-1953	Cairns 2005
	Plexauridae	***Swiftia exserta***	Straits of Florida, Bahamas, **Puerto Rico**, Mexico, Panama, southern Caribbean	18-494	Veronique 1987; Cairns 2005
	Plexauridae	*Swiftia koreni*	Straits of Florida, Guadeloupe	221-858	Veronique 1987; Cairns 2005

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
	Plexauridae	***Swiftia pallida*** (=*Thesa nivea*)	Straits of Florida, Guadeloupe	23-366	Humann 1993; Veronique 1987; Cairns 2005
	Plexauridae	*Swiftia pourtalesii*	Straits of Florida	>200	Cairns 2005; Watling and Auster 2005
	Plexauridae	*Swiftia sp. Sensu*	Western Atlantic	>200	Cairns 2005
	Keroeididae	*Thelogorgia longiflora*	Western Atlantic	>200	Cairns 2005
	Keroeididae	*Thelogorgia studeri* (=*Lingnella richardii*)	Saint Vincent, Guadeloupe, Barbados	180->200	Veronique 1987; Bayer 1961; Cairns 2005
	Keroeididae	*Thelogorgia vossi*	Western Atlantic	>200	Cairns 2005; Reyes et al. 2005
	Plexauridae	*Thesea antiope*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Thesea bicolor*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Thesea gracilis*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Thesea grandiflora*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Thesea grandiflora* var. *rugulosa*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Thesea grandulosa*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Thesea guadelupensis*	Guadeloupe	>200	Cairns 2005; Veronique 1987
	Plexauridae	*Thesea hebes*	Guadeloupe	275	Cairns 2005; Veronique 1987
	Plexauridae	*Thesea parviflora*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Thesea rugosa*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Thesea solitaria*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Thesea sp. Sensu*	Western Atlantic	>200	Cairns 2005
	Primnoidae	*Thouarella bipinnata*	Western Atlantic	>200	Cairns 2005; Cairns and Bayer 2006
	Primnoidae	*Thouarella diadema*	Western Atlantic	>200	Cairns 2005; Cairns and Bayer 2006
	Primnoidae	*Thouarella grasshoffi*	Western Atlantic	>200	Cairns 2005; Cairns and Bayer 2006

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
	Anthothelidae	***Titanideum frauenfeldii*** (=*T. suberosum*)	Straits of Florida, Cuba	15-238	South Atlantic Fishery Management Council, 1998; Cairns 2005
	Chrysogorgiidae	*Trichogorgia n. sp.*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Villogorgia antillarum*	Western Atlantic	>200	Cairns 2005
	Plexauridae	*Villogorgia n. sp.*	Western Atlantic	>200	Cairns 2005
	Plexauridae	***Villogorgia nigrescens***	Martinique, Guadeloupe, Colombia	176-275	Veronique 1987; Cairns 2005; Reyes et al. 2005
Order Helioporacea					
	Lithotelestidae	*Epiphaxum micropora*	Barbados	50-400	Bayer & Muzik 1977, 1979
Order Pennatulacea					
	Anthoptilidae	*Anthoptilum grandiflorum*	Southern Lesser Antilles	1600	Keller et al. 1975
	Funiculinidae	***Funiculina quadrangularis***	Venezuela	~30-4000	Keller et al. 1975; Picton and Howsen 2002
	Kophobelemnidae	*Kophobelemnon irregulatus*	Southeastern Caribbean Sea Basin	4160	Keller et al. 1975
	Renillidae	*Renilla reniformis*	Throughout Caribbean, including **Puerto Rico**	to 108 or more	Gosner 1978; Bayer 1961; NOAA 2005
	Umbellulidae	*Umbellula thomsoni*	Puerto Rico Trench Caribbean Sea Basin, Cayman Islands	1336-6200	Pasternak 1975
	Umbellulidae	*Umbellula durissima*	Southeastern Caribbean (Venezuela)	~1012-4400	Pasternak 1975; Keller et al. 1975
	Umbellulidae	*Umbellula hemigymna*	Southern Lesser Antilles, Caribbean Sea Basin	~2610-3500	Pasternak 1975
	Umbellulidae	*Umbellula magniflora*	Caribbean Sea Basin	~100-6300	Pasternak 1975; Keller et al. 1975
Class Hydrozoa					
Order Stylasterina					
	Stylasteridae	*Crypthelia glossopoma*	Straits of Florida, Yucatan Channel, Lesser Antilles, including **U.S. territories**	198-864	Cairns 1986
	Stylasteridae	*Crypthelia insolita*	Southernmost Lesser Antilles	159-720	Cairns 1986
	Stylasteridae	*Crypthelia papillosa*	Lesser Antilles	161-545	Cairns 1986

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
	Stylasteridae	*Crypthelia peircei*	Greater and Lesser Antilles, including **U.S. territories**	159-837	Cairns 1986
	Stylasteridae	*Crypthelia tenuisepata*	Lesser Antilles, including **U.S. territories**	761-1061	Cairns 1986
	Stylasteridae	*Distichopora anomala*	Lesser Antilles	139-311	Cairns 1986
	Stylasteridae	*Distichopora barbadensis*	Southernmost Lesser Antilles	102-311	Cairns 1986
	Stylasteridae	*Distichopora cervina*	Lesser Antilles, **Puerto Rico**	68-384	Cairns 1986
	Stylasteridae	*Distichopora contorta*	Only off Havana	125-368	Cairns 1986
	Stylasteridae	*Distichopora foliacea*	Straits of Florida, Yucatan Channel	183-366	Cairns 1986
	Stylasteridae	*Distichopora rosalindae*	Western Caribbean	165-198	Cairns 1986
	Stylasteridae	***Distichopora sulcata***	Only off Havana, Cuba	1097	Cairns 1986
	Stylasteridae	*Distichopora uniserialis*	Only off Havana, Cuba	333-366	Cairns 1986
	Stylasteridae	*Distichopora yucatanensis*	Western Caribbean	39-261	Cairns 1986
	Stylasteridae	*Errina altispina*	Only Yucatan Channel	198-309	Cairns 1986
	Stylasteridae	*Errina cochleata*	Straits of Florida, Bahamas	194-534	Cairns 1986
	Stylasteridae	*Lepidopora biserialis*	Straits of Florida	196-370	Cairns 1986
	Stylasteridae	*Lepidopora carinata*	Only off Havana	60-494	Cairns 1986
	Stylasteridae	*Lepidopora clavigera*	Only off Barbados	150-282	Cairns 1986
	Stylasteridae	*Lepidopora decipiens*	Lesser Antilles	270-670	Cairns 1986
	Stylasteridae	*Lepidopora glabra*	Only off Havana	267-1170	Cairns 1986
	Stylasteridae	*Lepidotheca brochi*	Dominica, Martinique, Montserrat, Saint Kitts and Nevis	545-864	Cairns 1986
	Stylasteridae	*Lepidotheca pourtalesi*	Straits of Florida	123-368	Cairns 1986
	Stylasteridae	*Pliobothrus echinatus*	Lesser Antilles and Mona Passage, including **Puerto Rico**	164-708	Cairns 1986
	Stylasteridae	*Pliobothrus symmetricus*	Throughout Caribbean, including **Puerto Rico**	150-400	Cairns 1986
	Stylasteridae	*Pliobothrus tubulatus*	Antilles, including **U.S. territories**	419-708	Cairns 1986
	Stylasteridae	*Stenohelia pauciseptata*	Only off St. Lucia	300-514	Cairns 1986

Higher Taxon	Family	Species ▲	Distribution ♠	Depth Range	Reference ‡
	Stylasteridae	*Stylaster antillarum*	Lesser Antilles and the Mona Passage, including **Puerto Rico**	174-653	Cairns 1986
	Stylasteridae	*Stylaster atlanticus*	Only off **Puerto Rico** (Isla de Culebra)	823	Cairns 1986
	Stylasteridae	*Stylaster auranticus*	Greater Antilles, off Cuba	112-377	Cairns 1986
	Stylasteridae	*Stylaster complanatus*	Straits of Florida, Antilles, including **U.S. territories**	183-707	Cairns 1986
	Stylasteridae	*Stylaster corallium*	Barbados, Dominica, Grenada, Martinique, Saint Lucia	13-298	Cairns 1986
	Stylasteridae	*Stylaster duchassaingi*	Widespread Caribbean, including **U.S. Virgin Islands**, Bahamas	42-692 (common 200-400)	Cairns 1986
	Stylasteridae	*Stylaster erubescens*	Continental slopes of the southeasetern United States to the Yucatan Peninsula	146-965	Cairns 1986
	Stylasteridae	*Stylaster filogranus*	Straits of Florida	183-274	Cairns 1986
	Stylasteridae	*Stylaster inornatus*	Only off the Yucatan Peninsula	198-309	Cairns 1986
	Stylasteridae	*Stylaster laevigatus*	Straits of Florida, Yucatan Channel	123-759 (common 300-400)	Cairns 1986
	Stylasteridae	*Stylaster miniatus*	Straits of Florida	146-530	Cairns 1986
	Stylasteridae	*Stylaster profunda*	Lesser Antilles, including **Puerto Rico**	159-2021 (common 200-650)	Cairns 1986
	Stylasteridae	*Stylaster roseus*	Widespread Caribbean, including **Puerto Rico**	0.5-373 (common 0.5-30)	Cairns 1986
	Stylasteridae	*Stylaster spatula*	Only off southeastern **Puerto Rico**	384-549	Cairns 1986

Appendix 8.2. An aggregate inventory of the benthos associated with the major structure-forming corals *E. profunda*, *L. pertusa*, *M. carolina*, *M. oculata*, and *S. varibilis* throughout the wider Caribbean. Benthos is grouped by coral species. Sources include station data from 28 locations in the wider Caribbean, sampled by the following research vessels: R/V *Pillsbury* (14 Stations); R/V *Columbus Iselin* (5 Stations); R/V *Gerda* (6 Stations); R/V *Gilliss* (1 Station); Submersible Alvin (multiple station); and R/V *Eastward* (multiple stations) (Anon 1963; 1964, 1965, 1966, 1968, 1969, 1970, 1972a, 1972b, 1973, 1974; Bayer 1966; Staiger 1968a, 1968b, 1969, 1971; Voss 1966a and 1966b). Locations are identified in Figure 3 by the letter S (some station locations overlap). *Please note that many species noted were first identifications and spelling is presented as it appears on the original station sorting sheets.

Potential structure and habitat- forming species	Other coelenterata	Crustacean (deep-seas crabs, shrimp and lobsters)	Fish	Echinoderms	Mollusks	Other
E. profunda						
L. pertusa; *S. varibilis*; gorgonians; hydroids; octocorals	"Solitary corals"; "Medusae"	*Homolodramia paradoxa*; *Galatheid* sp.; *Pylocheles scutata*; *Glyphocrangon longleyi*; *Nephropsis rosea*; *Plesionika acanthonotus*; *Pasiphaeidae* sp.; *Stylirostris* sp.; *Nematocarcinua cursor*; isopods	*Benthobatis* sp.; *Breviraja plutonia* (ray); *Cruriraja* sp. (skates); *Etmopterus* sp. (dogfish sharks); *Laemonema* sp. (hake); *Synaphobranchus* sp.; *Nettastomatidae* sp. (eels)		Gastropods; pelecypods; scaphopods; brachiopods	Polychaetes; porifera; pyncnogonids
L. pertusa						
S. varibilis; *E. profunda*; gorgonians; "corals"	"Solitary corals"; actinarians	*Aristaeomorpha* sp.; *Bathyplax* sp.; *Benthochascon* sp.; *Crangonidae* sp.; *Galatheid* sp.; *Hymenopenaeus* sp.; *Munida* sp.; *Munidopsis* sp.; *Nephropsis* sp.; *Palicus* sp.; *Phoberus* sp.; *Polycheles* sp.; *Raninoides* sp.; *Rochinia* sp.; *Stereomastis* sp.; *Stylirostris* sp.; *Xanthidae* sp.	*Bathyclupea* sp. (deepsea herring); *Bembrops* sp.; *Benthobatis* sp.; *Breviraja plutonia* (ray); *Brotulid* sp. (fangtooths); *Chaunax pictus* (anglerfish); *Chlorophthalmus* sp.; *Cruriraja* sp. (skates); *Dibranchus* sp. (batfishes); *Etmopterus* sp. (dogfish shark); *Gadidae* sp (cod) ; *Galeus* sp. (benthic sharks); *Laemonema* sp. (hake); *Macrourid* sp. (grenadiers); *Merluccius* sp. (hake); *Moridae* sp. (deepsea codfishes); *Neoscopelus* sp. (lanternfish); *Nettastomid* sp.; *Promyllanter schmitti*; *Synaphobranchus* sp.	Holothurians (sea cucumbers); Nymphaster sp.; Ophiuroids; Phormosoma sp.; Zoroaster sp.	Arca sp.; Columbarium sp.; Gastropods; Gaza sp.; Natica sp.; Turridae sp.; Voluta sp.; Xenophora sp.	Polychaetes; porifera

Potential structure and habitat- forming species	Other coelenterata	Crustacean (deep-seas crabs, shrimp and lobsters)	Fish	Echinoderms	Mollusks	Other
M. carolina						
"Corals"; *Antipatharia* sp. (black corals); *Stylasterina* sp. (hydrocorals)	"Solitary corals"; *Actiniaria* sp. (anemones); *Alcyonaria* sp. (soft corals); Hydroids; *Urochordata* sp. (encrusting gorgonians); zoanthids	*Anomalothir furcillatus*; *Brachyura* sp.; *Cancellus oratus*; *Cirripedia* sp.; *Clibanarius anomalus*;; *Galatheid* sp.; *Homaridae* sp.; *Iliacantha subglobosa*; *Leucosiidae* sp.; *Majidae* sp.; *Munida irrasa*; *Munida schroederi* ; *Myropsis quinquespinosa*; *Nephropsis aculeate*; *Paguristes spinipes; Pandalidae sp.; Plesionika acanthonotus; Podochela curvirostris ; Pyromia cuspidate; Sicyonia stimpsoni; stomatopods; Sympagurus pictus*	*Calamopteryx goslinei*; elasmobranch egg cases	Asteroidea; crinoids; echinoids; holothurians (sea cucumbers); ophiuroids; starfish; brittle stars; urchins	Gastropods; pelecypods; brachiopods	Algae; "Large sponge 18" across"; oolite chunk; polychaetes; bryozoans; tunicates

Potential structure and habitat- forming species	Other coelenterata	Crustacean (deep-seas crabs, shrimp and lobsters)	Fish	Echinoderms	Mollusks	Other
M. oculata						
S. varibilis; "pink gorgonians"; "various coelenterates"; *Acanella* sp. (bamboo corals); *Bathypathes patula*; *Calytrophora pourtalesi* (sea fan / sea whip); *Chrysogorgia* sp. (sea fan / sea whips); *Cirripathes* sp. (sea whips); gorgonians; *Iridogorgia* sp. (spiral corals); *Keratoisis* sp.; *Plumarella* sp.	"Solitary corals"; Deltocyathus sp.; Desmophyllum sp.; Hydroids; Odontocyathus coronatus; Pennatulidae sp. (sea pens); Stephanocyathus diadema; Telestula sp. (anemones); aoanthids	"Various crustaceans"; *Acanthephyra* sp.; *Amphipods*; *Aristaeinae* sp.; *Aristeus* sp.; *Axiidae* sp.; *Bathymunida* sp.; *Bathypalaemonella* sp.; *Bathyplax* sp.; *Bathysquilla* sp.; *Galatheid* sp.; *Gennadas* sp.; *Glyphocrangon* sp.; *Gnathophausia* sp.; *Heterocarpus* sp.; isopods; *Lithodid* sp.; *Majidae* sp.; *Munida* sp.; *Munidopsis* sp.; *Nematocarcinus* sp.; *Nephropsis* sp.; *Oplophorus* sp.; *Pandalidae* sp.; *Parapagurus* sp.; *Plesiopenaeus* sp.; *Polycheles crucifer*; *Polychelidae* sp.; *Pontophilus* sp.; *Prionocrangon* sp.; *Scalpellum* sp.; *Sergestes* sp.; *Spongicoloides* sp.; *Stereomastis* sp.; *Stylodactylus* sp.; *Uroptychus nitidus*; *Uroptychus* sp; *Uroptychus* sp.; *Verrucomorphs* sp.	*Acanthurus* sp. (surgeonfish); *Alepocephalus* sp.; *Apristurus* sp. (cat sharks); *Barathronus* sp. (cusk-eels); *Bathypterois* sp. (tripod fish); *Benthobatis* sp.; *Brotulid* sp. (fangtooths); *Chaunax pictus* (anglerfish); *Diaphus* sp. (headlightfish); *Dibranchus atlanticus* (Atlantic batfish); *Dibranchus* sp. (batfishes); *Dicrolene intronigra; Diretmus sp. (dorys); Gonostomatidae sp. (bristlemouth); Halosaurs sp.; Hariotta sp. (chimaera); Ilyophis sp. (eels); Macrourid sp. (grenadiers); Monomitopus sp. (cusk-eels); Myctophid sp. (lanternfish); Myxini sp. (hagfish); Neoscopelus sp. (lanternfish); Nesiarchus sp. (scabbardfish); Notacanthid sp. (spiny eel); Oxygadus sp. (rattails); Promyllantor schmitti; Saurida sp. (lizardfish); Searsid sp.; Sternoptychidae sp. (hatchetfish); Stomias sp. (dragon fish); Synaphobranchus oregoni Synaphobranchus sp.*	"Pancake urchin"; "Soft urchin"; asteroids; *Benthopectinids; Crinoids; Goniaster sp.; holothurians (sea cucumbers); Molpadia sp. (sea cucumbers); Nymphaster sp.; ophuiroids; Phormosoma sp. (sea biscuts); Psilaster squameus; Zoroaster fulgens*	"Squid, unidentified"; *Acesta* sp. (Clams); *Arenatus* sp.; *Gaza superba*; *Leptothyra* sp.; *Leucosyrinx* sp.; *Limopsis* sp.; *Melongena* sp; *Mitra* sp.; *Pseudamusium dallil* (bivalve, clam?); scaphopods; *Solariella* sp.; solenogaster (shelless mollusk); *Spirula spirula*; *Turridae* sp.	"Grapefruit sponges"; *Cladorhiza* sp (potato sponges); *Hexactinellida* sp. (glass sponges); *Hyalonema* sp.; polychaetes

Potential structure and habitat- forming species	**Other coelenterata**	**Crustacean (deep-seas crabs, shrimp and lobsters)**	**Fish**	**Echinoderms**	**Mollusks**	**Other**
S. varibilis						
M. oculata; L. *pertusa*; *E. profunda*; "corals"; *Acanella sp.* (bamboo corals); *Callogorgia* sp.; *Chrysogorgia* sp. (sea fan / sea whips)*; Keratoisis* sp. (bamboo corals); *Nicella* sp.; octocorals; Primnosis sp.	"Solitary corals"; *Odontocyathus coronatus*; *Stephanocyathus diadema*; *Telestula* sp. (anemones); *Clavulariidae* sp.	*Acanthephyra* sp.; amphipods; *Aristaeinae* sp.; *Axiidae* sp.; *Chirostylus* sp.; *Galatheid* sp.; *Gennadas* sp.; *Glyphocrangon aculeate*; *Glyphocrangon alispina*; *Glyphocrangon* sp.; *Heterocarpus* sp.; isopods; *Lithodid* sp.; *Majidae* sp.; *Mixtopagurus paradoxus*; *Munida* sp.; *Munidopsis* sp.; *Nematocarcinus* sp.; *Nephropsis* sp.; *Oplophorus* sp.; *Paguristes* sp.; *Penaeid* sp.; *Polycheles crucifer*; *Polychelidae* sp.; *Prionocrangon* sp.; *Processa* sp.; *Pylopagurus* sp; *Rochinia* sp.; *Sergestes* sp.; *Spongicoloides* sp.; *Stereomastis* sp.; *Stylodactylus* sp.; *Systellaspis* sp.; *Uroptychus* sp.	*Brotulid* sp. (fangtooths); *Callionymus* sp.; *Chaunax* sp. (Anglerfish); *Chlorophthalmus* sp.; *Dibranchus atlanticus* (Atlantic batfish); *Gadomus longifilis* (Bathygadid family); *Hymenocephalus* sp. (rattails); *Macrourid* sp. (grenadiers); *Monomitopus* sp. (cusk-eels); *Peristedion* sp. (sea robins); *Promyllantor schmitti*; *Saurida* sp. (lizardfish)	*Ceramaster elongatus* (Cookie starfish); *Ceramaster* sp.; cidarids; *Circeaster americanus*; *Lophaster verrilli*; *Nymphaster* sp.; *Ophidiaster* sp.; *Solaster caribbea*; *Spatangoids*; *Zoroaster ackleyi*	"Finned octopod"; "unidentified squid"; *Acesta* sp. (Clams); brachiopods; *Dentalium* sp.; *Naticidae* sp.; *Ornithoteuthis antillarum* ; *Propeamusium dalli*; pteropods; scaphopods; *Solariella* sp.; *Solenogaster* sp.; *Turridae* sp.	Cladorhiza sp. (potato sponges); polychaetes; pyncnogonids

Appendix 8.3. Commercially important deep-sea fish of the wider Caribbean (FAO 1993).

Species	Depth (m)
Snappers:	
Apsilus dentatus (black snapper)	70 – 290
Etelis oculatus (queen or green snapper)	180 – 463
Lutjanus buccanella (blackfin snapper)	80 – 180
L. vivanus (silk snapper)	60 – 210
Rhomboplites aurorubens (vermilion snapper)	80 – 230
Sharks:	
Centrophorus granulosus (gulper shark)	to 210
Eugomphodus taurus (grey nurse shark)	to 210
Hexanchus vitulus (bigeyed sixgill shark)	to 250
Mustelus canis (smooth dogfish)	to 250
Scyliorhinus boa (catshark)	to 270
Sphyma lewini (scalloped hammerhead shark)	to 170
Squalus cubensis (Cuban dogfish)	to 300
Promthicthys Prometheus (rabbit-fish)	to 170
Groupers & hinds:	
Epinephelus adscensionis (rock hind)	0 – 120
E. flavolimbatus (yellowedge grouper)	to 132
E. fulvus (coney)	0 – 230
E. guttatus (red hind)	0 – 200
E. morio (red grouper)	to 174
E. mystacinus (misty grouper)	180 – 270
Mycteroperca phenax (scamp)	to 174
Neoscombrops sp.	to 190
Other:	
Erythrocles monody (Atlantic rubyfish)	to 300
Gephyroberix darwini	to 310
Ostichthys trachypoma (bigeye soldierfish)	to 290
Polymixia lowel (beardfish)	to 260
Pristipomoides sp. (jobfish)	180 – 300+

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