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

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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).

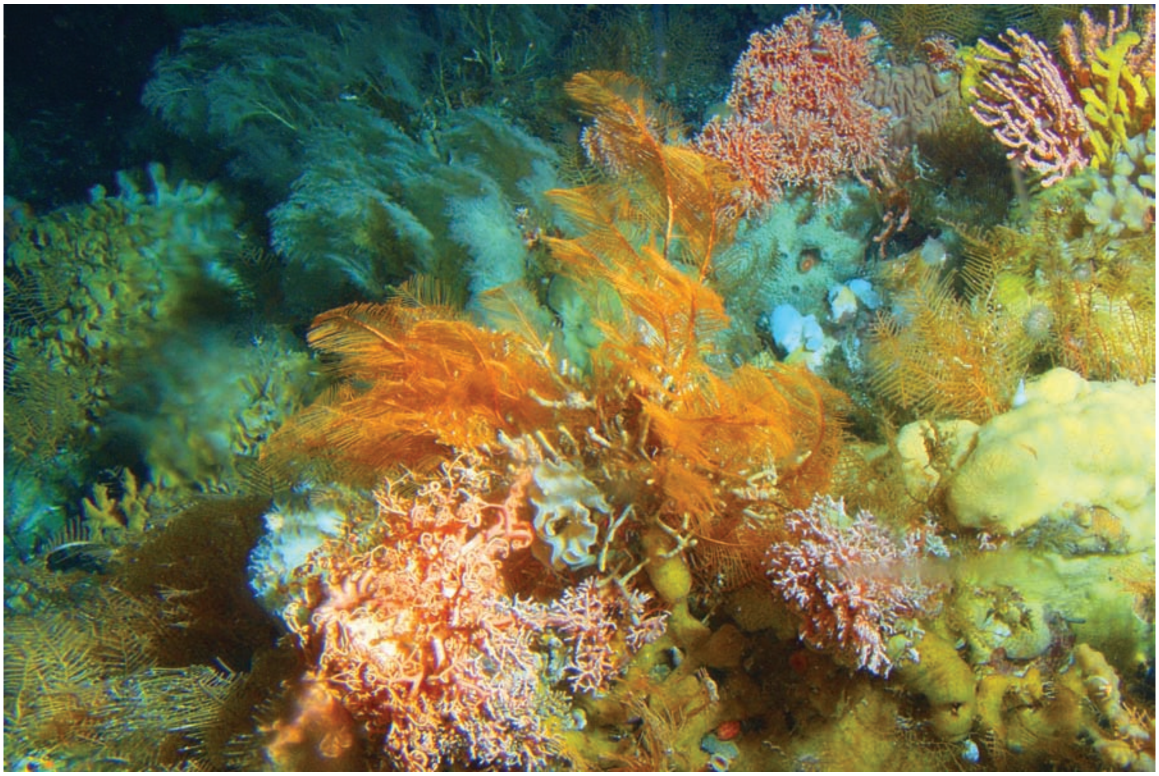

Figure 1.1 An Alaskan "coral garden" with several species of soft corals, hydrocorals, hydroids, and demosponges. Photo credit: Alberto Lindner

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.

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.

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

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).

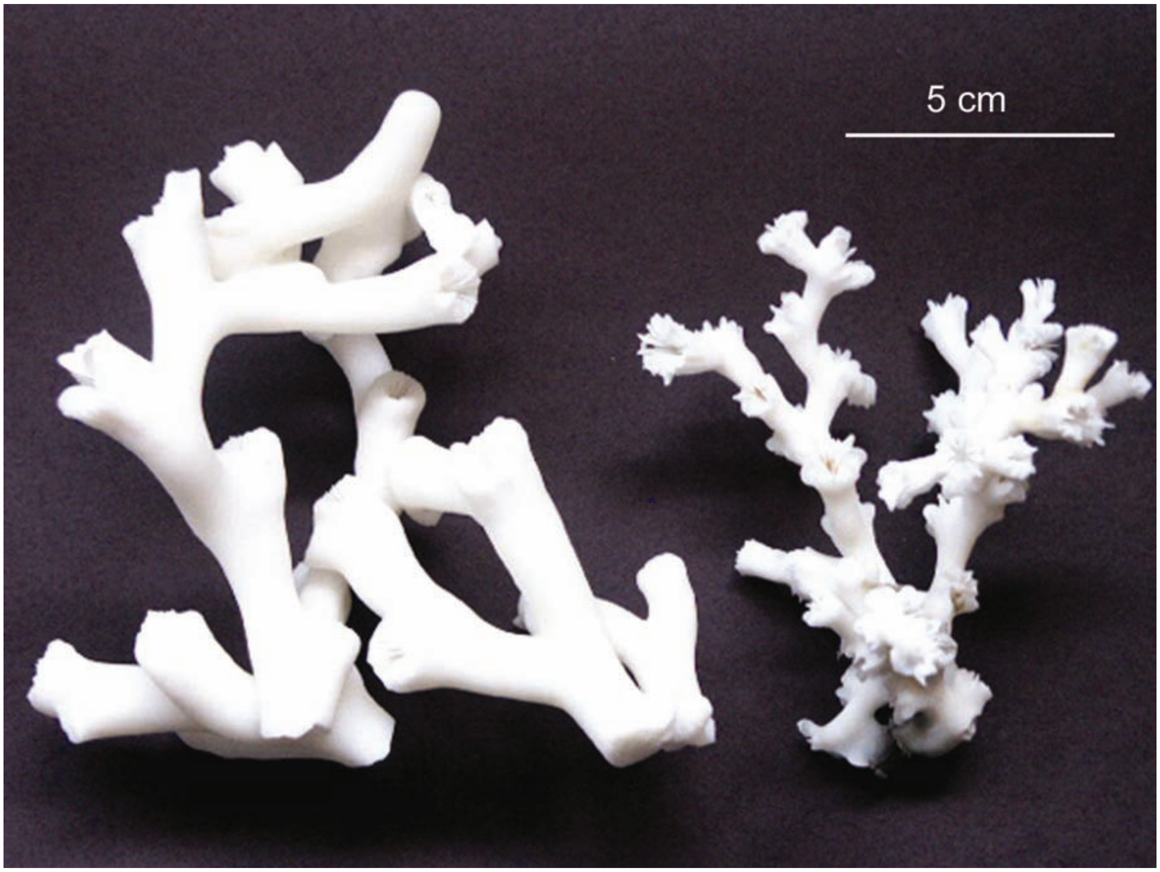

Figure 1.2 Samples of *Lopehlia pertusa* colonies collected from the Gulf of Mexico. The left specimen displays the more heavily calcified "brachycephala" morphology with large polyps, and the right specimen shows the more fragile "gracilis" morphology. Photo credit: Sandra Brooke, OIMB, Charleston,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

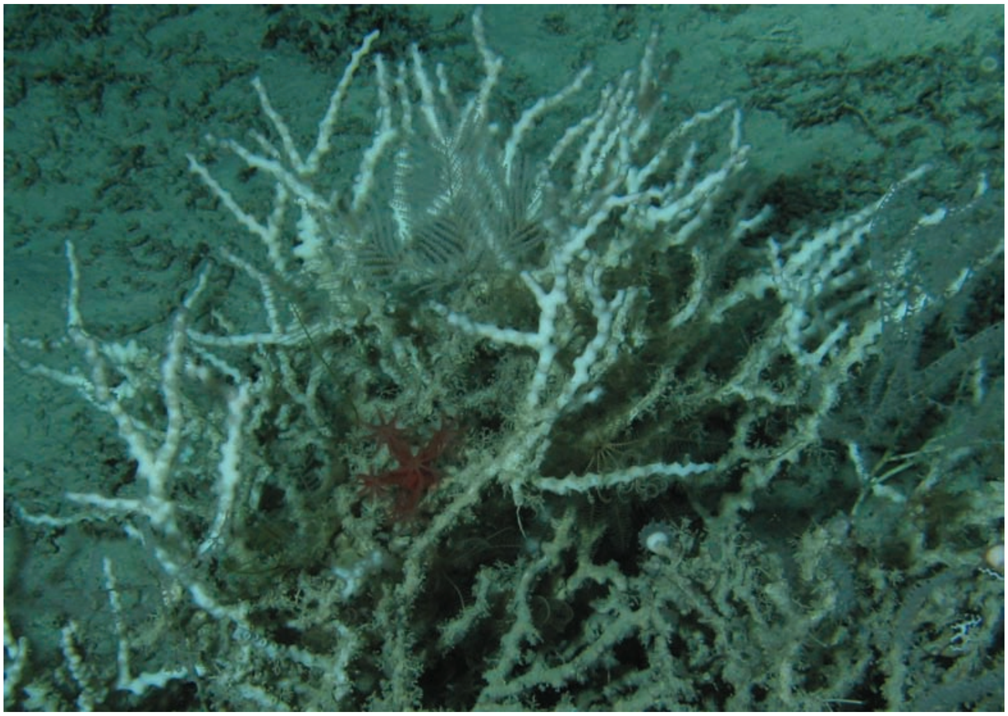

Figure 1.5 The deep coral *Enallopsammia profunda*. Photo credit: Brooke et al., NOAA-OE, HBOI.

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).

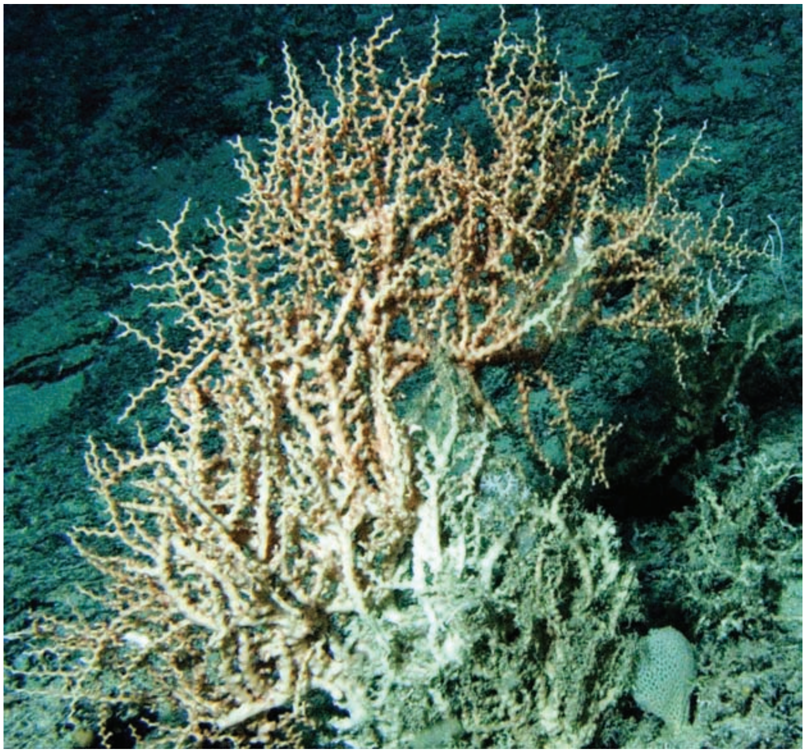

Figure 1.8a *Madrepora oculata* coral *in situ,* one of the three dominant corals that make up the deepwater reefs off Florida. Photo credit: Brooke et al, NOAA-OE, HBOI.

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*

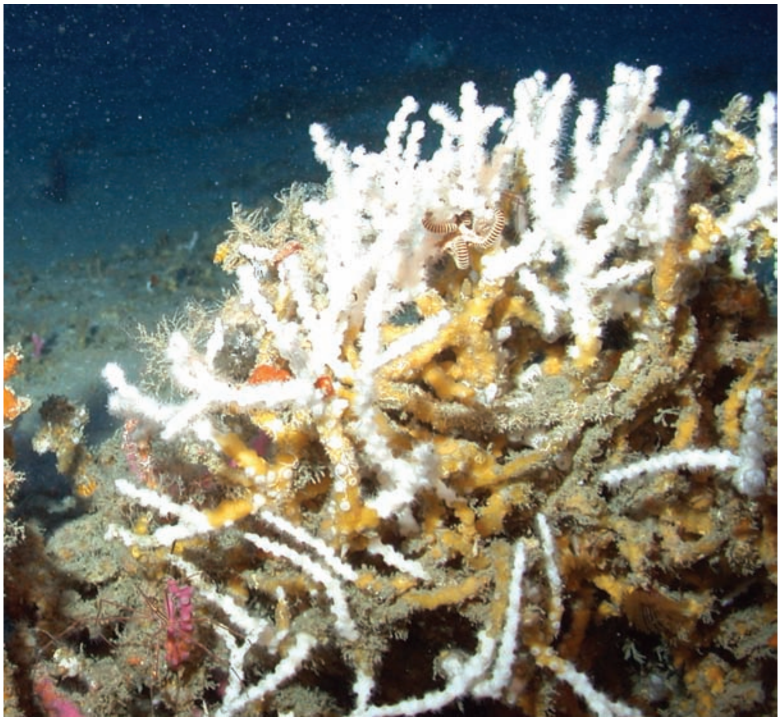

Figure 1.9 *Oculina varicosa* in the *Oculina* HAPC. Photo credit: L. Horn, NOAA Undersea Research Center at UNC-Wilmington.

(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

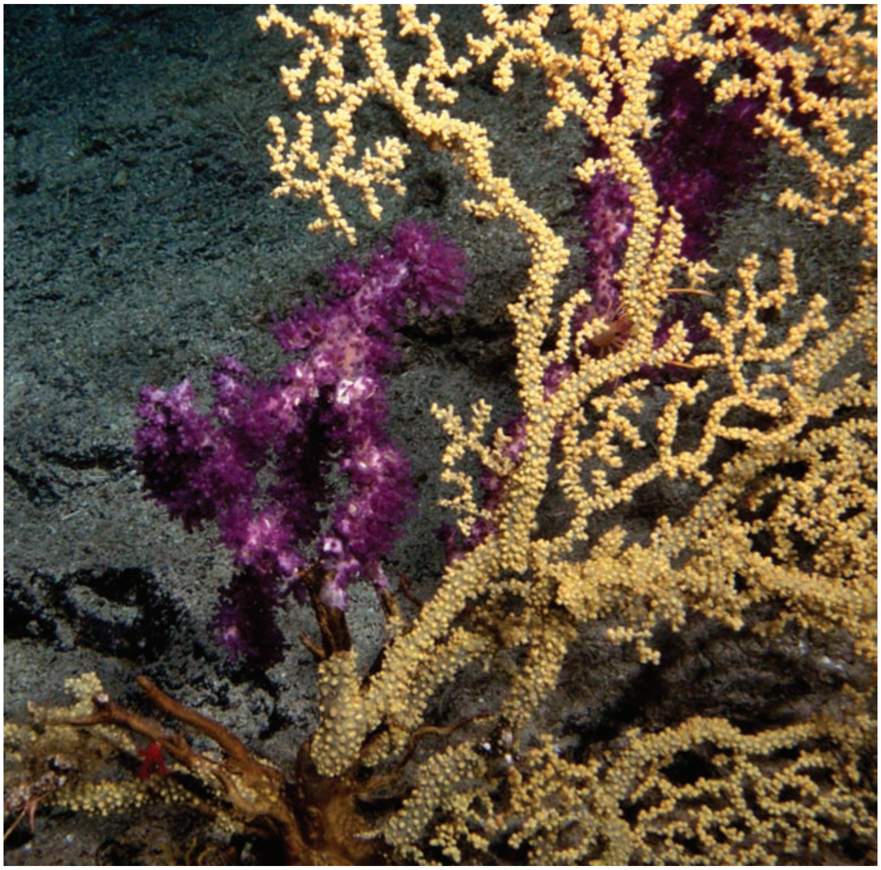

Figure 1.11 Gold coral (*Gerardia* sp.) in Hawaii with a purple octocoral *Clavularia grandiflora* growing on it. Photo credit: A. Baco.

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

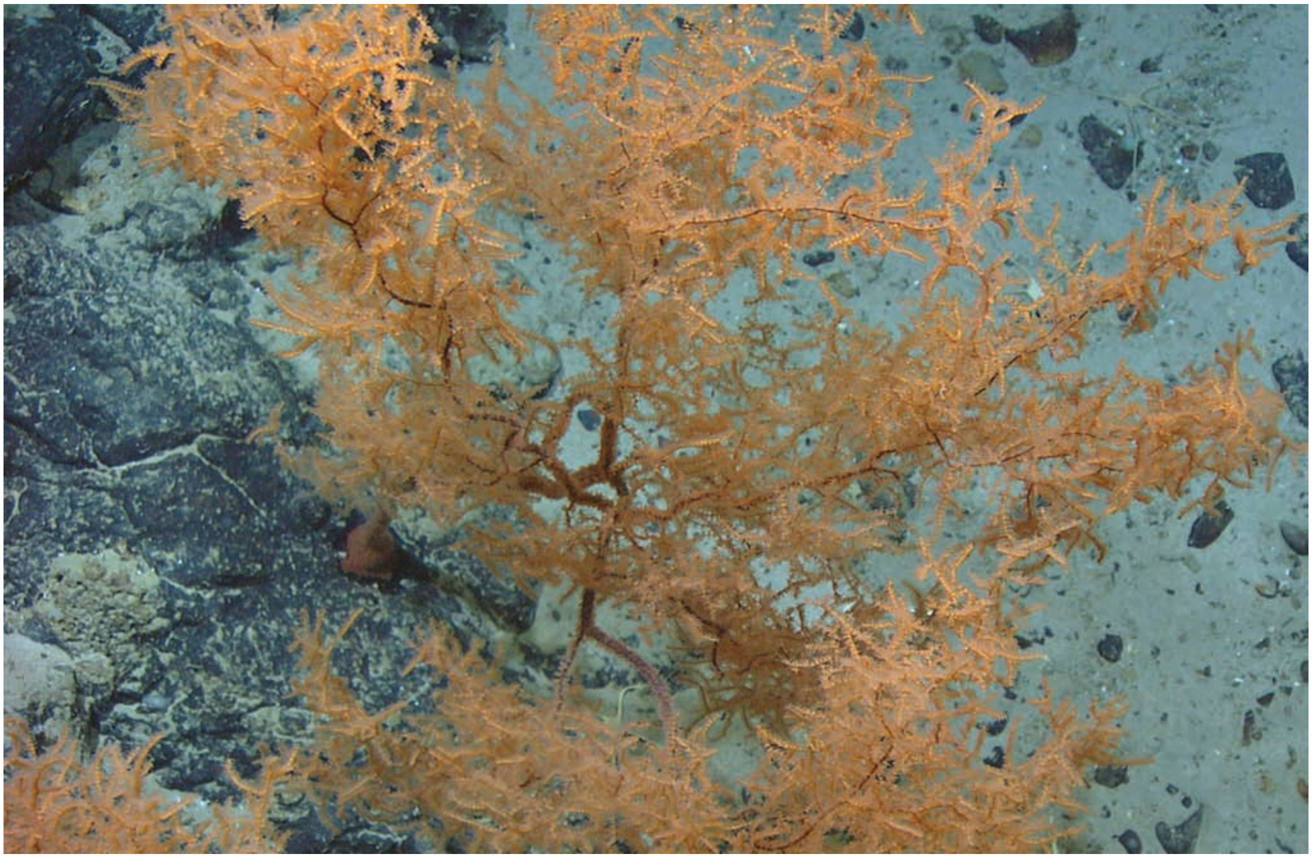

Figure 1.12 A bushy black coral on Manning Seamount. Photo credit: The Mountains in the Sea Research Team, the IFE crew, and NOAA-OE.

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

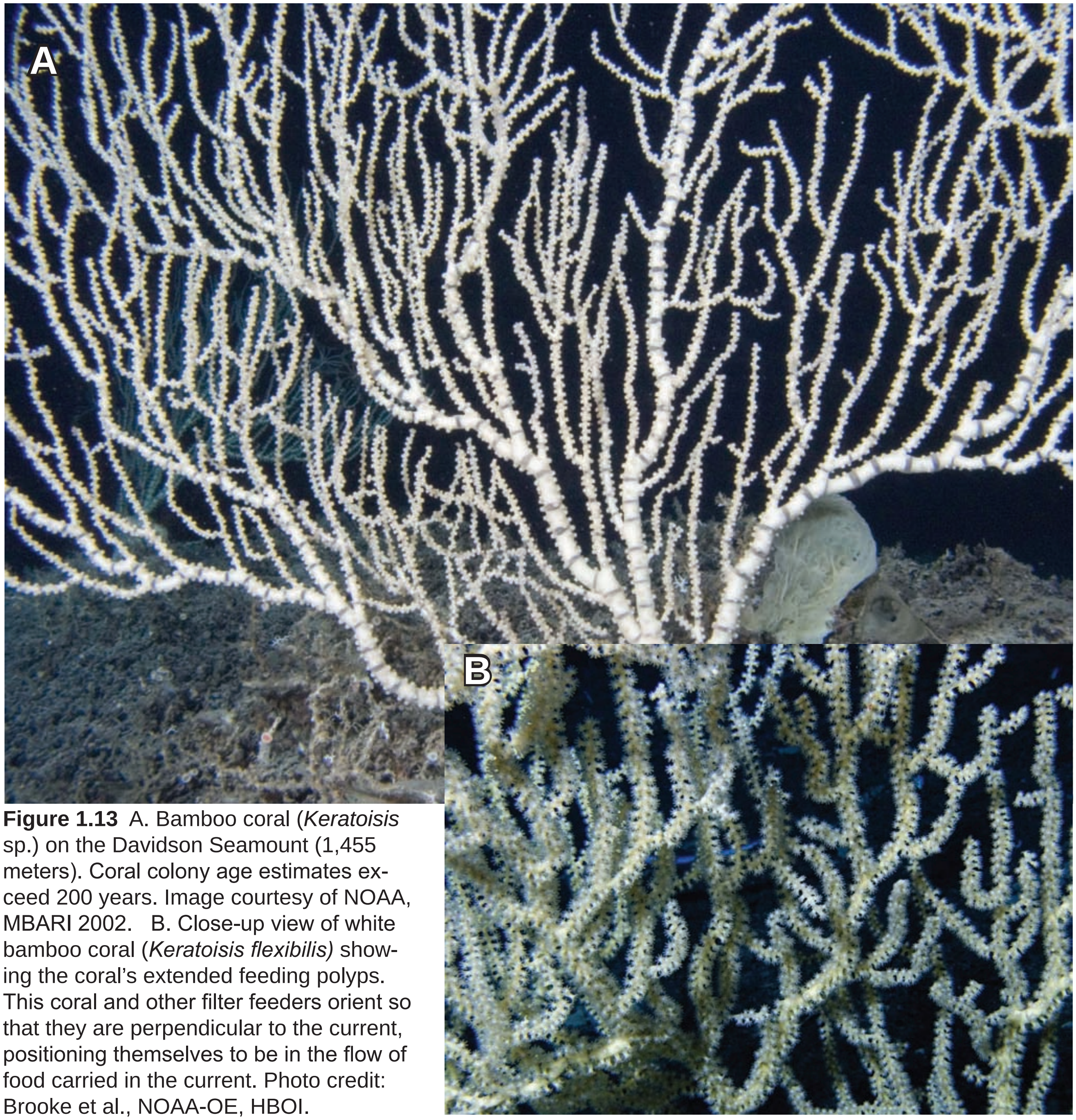

Figure 1.13 A. Bamboo coral (*Keratoisis* sp.) on the Davidson Seamount (1,455 meters). Coral colony age estimates exceed 200 years. Image courtesy of NOAA, MBARI 2002. B. Close-up view of white bamboo coral (*Keratoisis flexibilis)* showing the coral's extended feeding polyps. This coral and other filter 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 19° 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.*

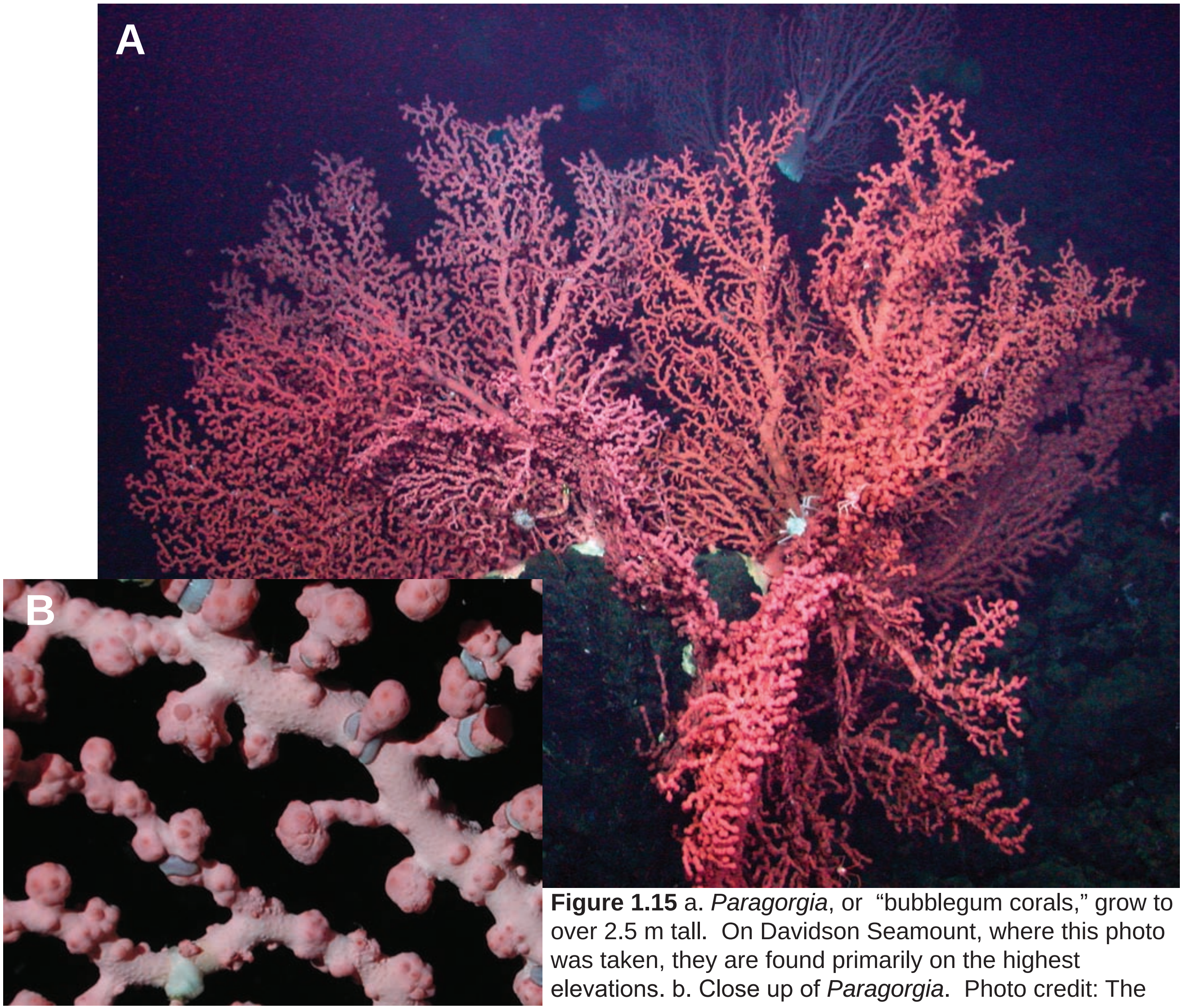

Figure 1.15 a. *Paragorgia*, or "bubblegum corals," grow to over 2.5 m tall. On Davidson Seamount, where this photo was taken, they are found primarily on the highest elevations. b. Close up of *Paragorgia*. Photo credit: The Davidson Seamount Expedition, MBARI, and NOAA-OE.

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).

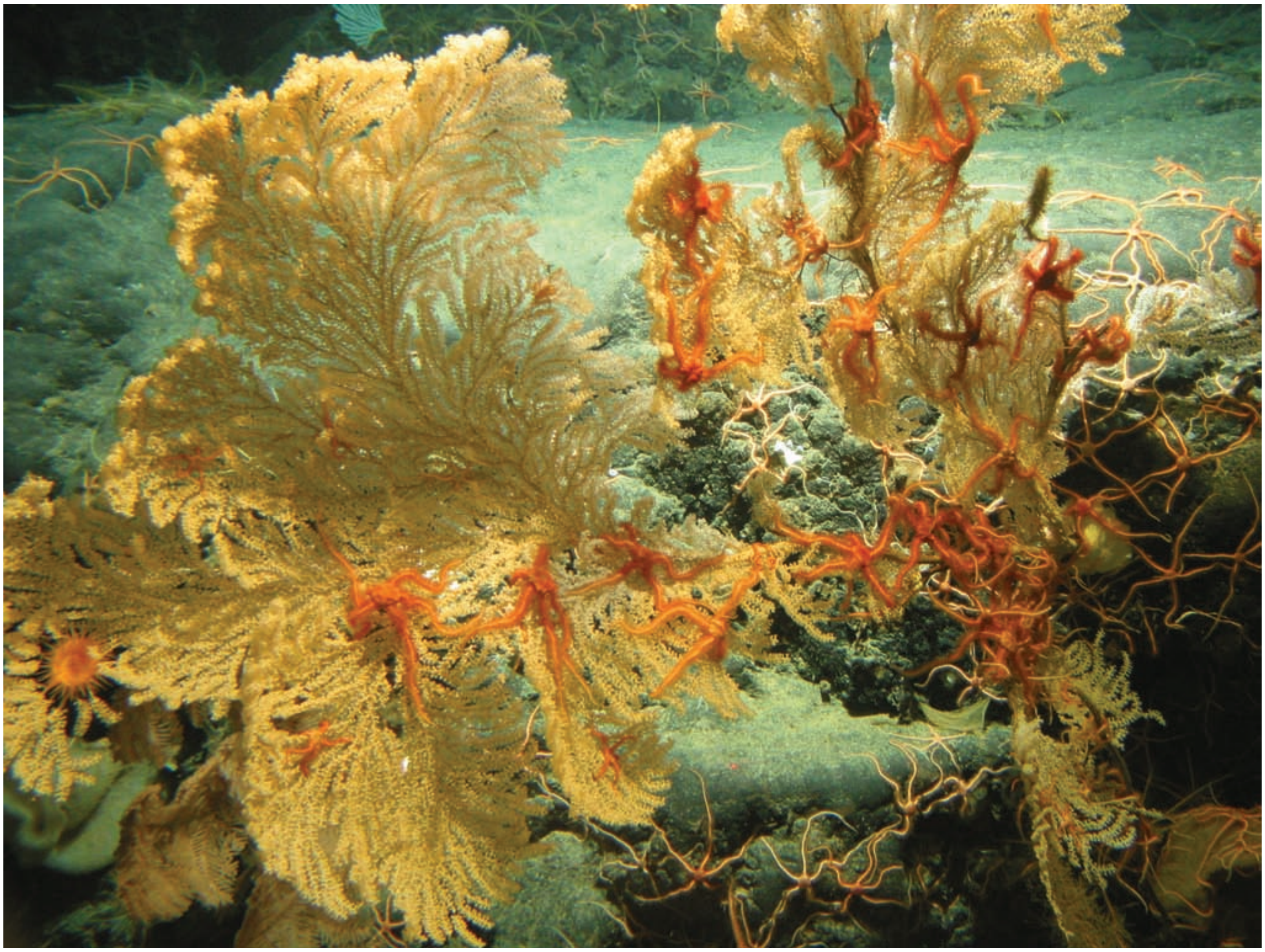

Figure 1.16. Large primnoid coral with associated brittle stars on Dickinson Seamount, Gulf of Alaska. Photo credit: The Gulf of Alaska Seamount Expedition, and NOAA-OE.

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).

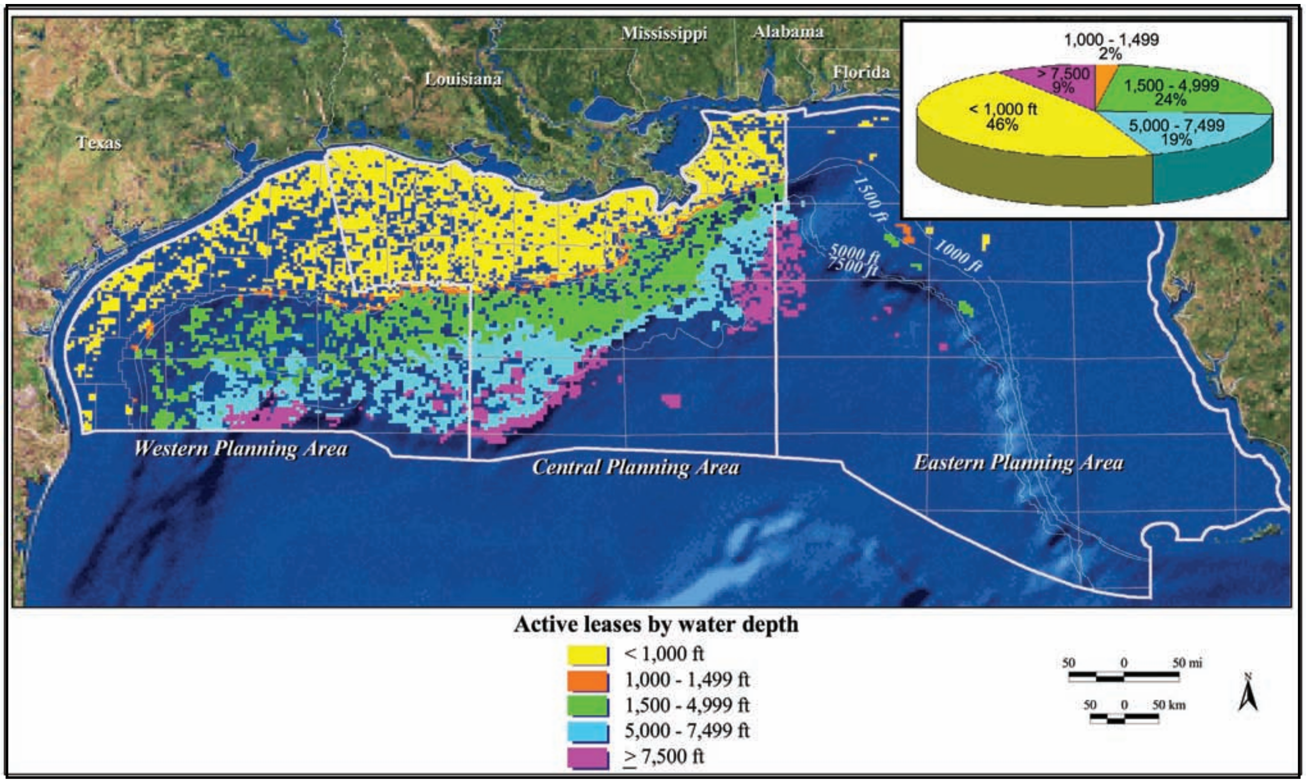

Figure 1.22 Map of the Gulf of Mexico showing active leases by water depth in 2005. Image credit: Minerals Management Service.

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/

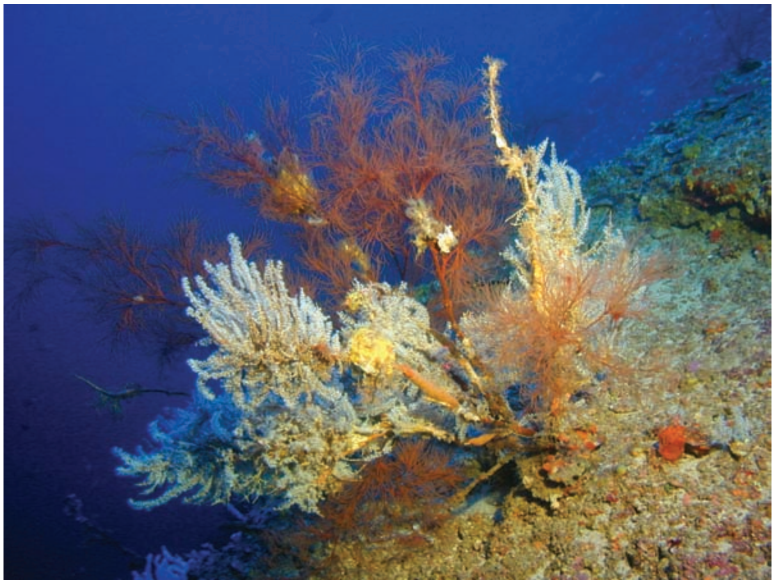

Figure 1.23 Black coral at approximately 100 m depth overgrown with the invasive snowflake coral *Carijoa riisei*. Photo credit: HURL (Hawaii Undersea Research Laboratory) archives, R. Grigg and S. Kahng.

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

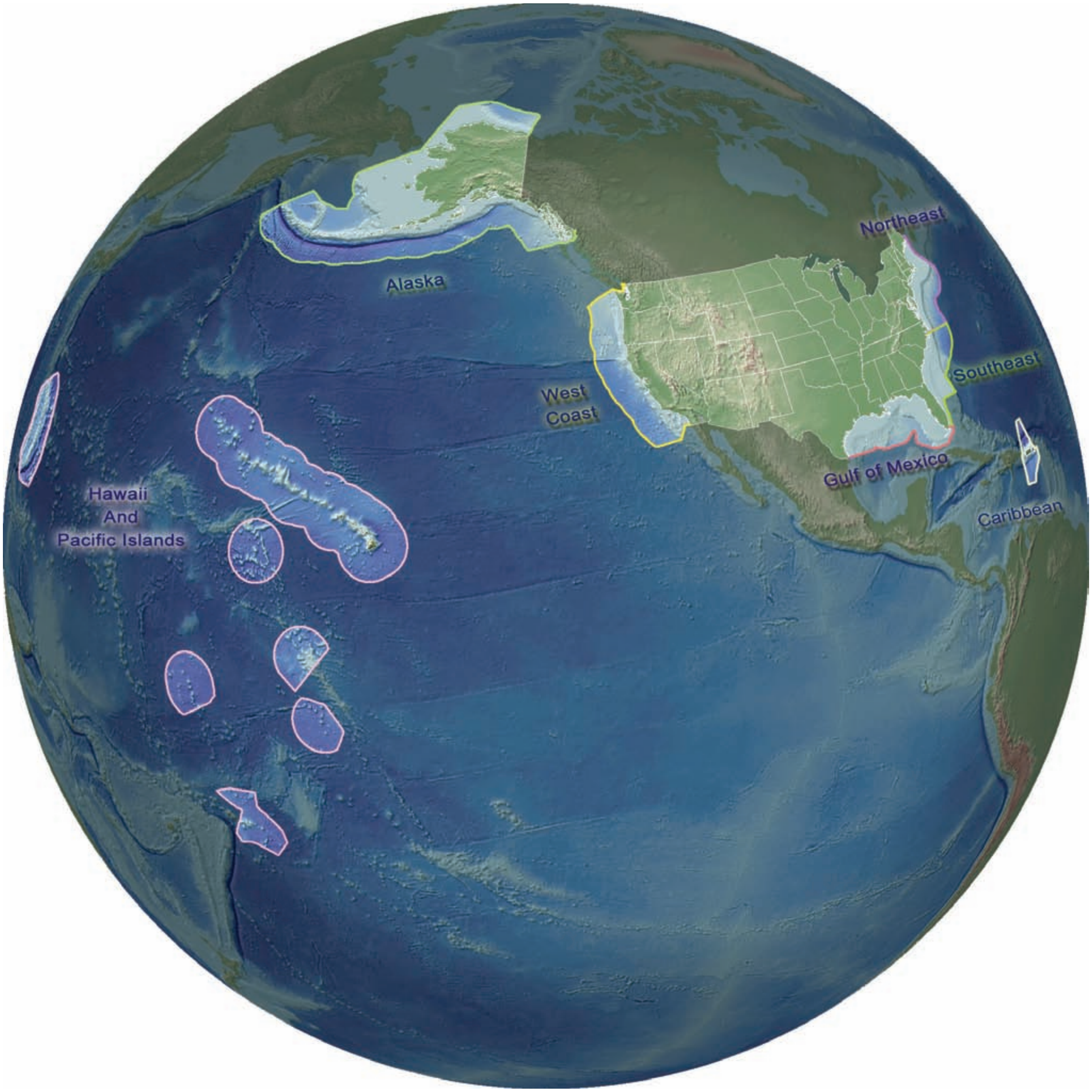

Figure 1.25 Map showing the U.S. EEZ and areas of seven regional assessments.

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

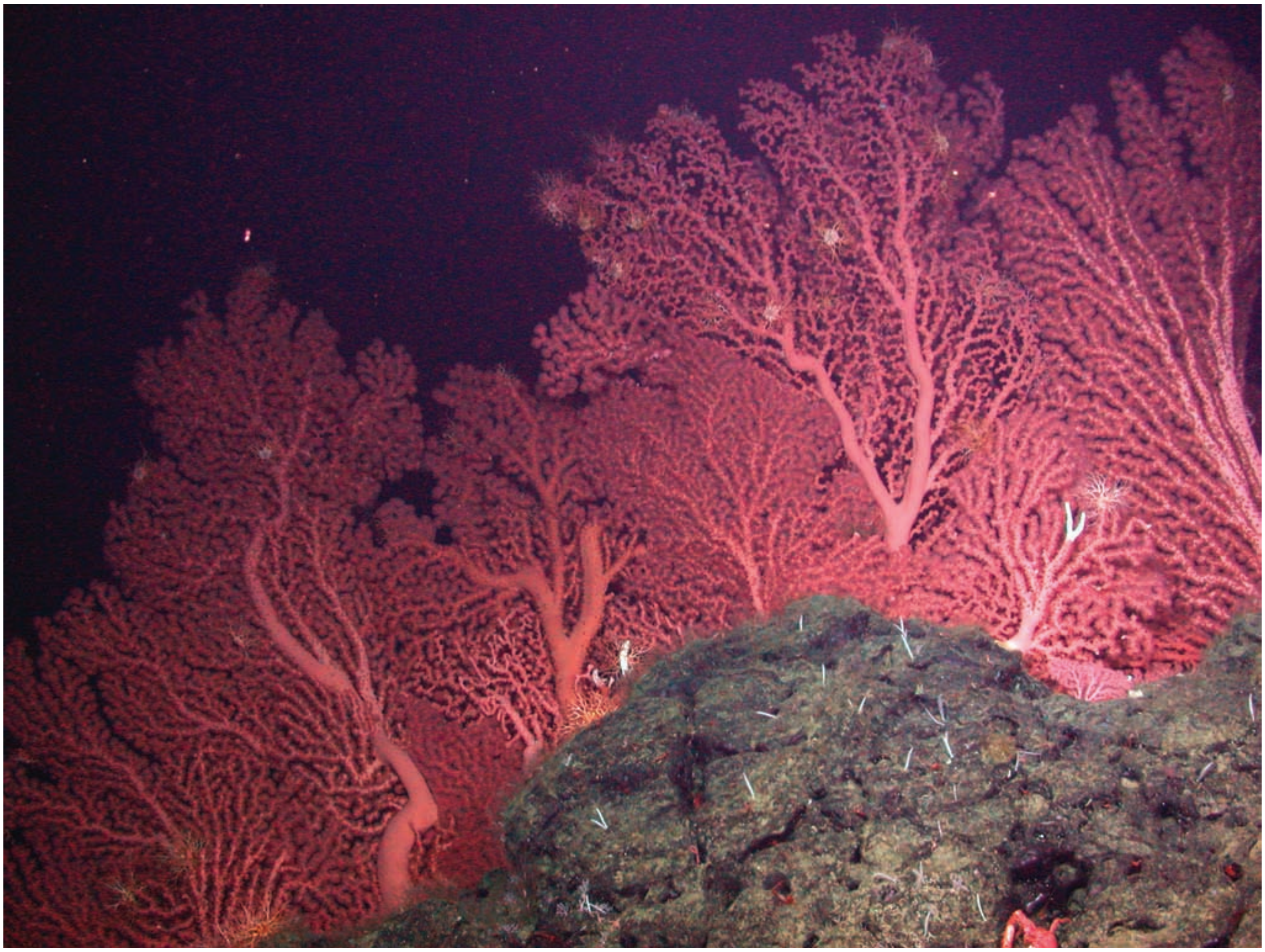

Figure 1.26 *Paragorgia* sp. crown a ridge on the Davidson Seamount. Photo credit: The Davidson Seamount Expedition, MBARI, and NOAA-OE.

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

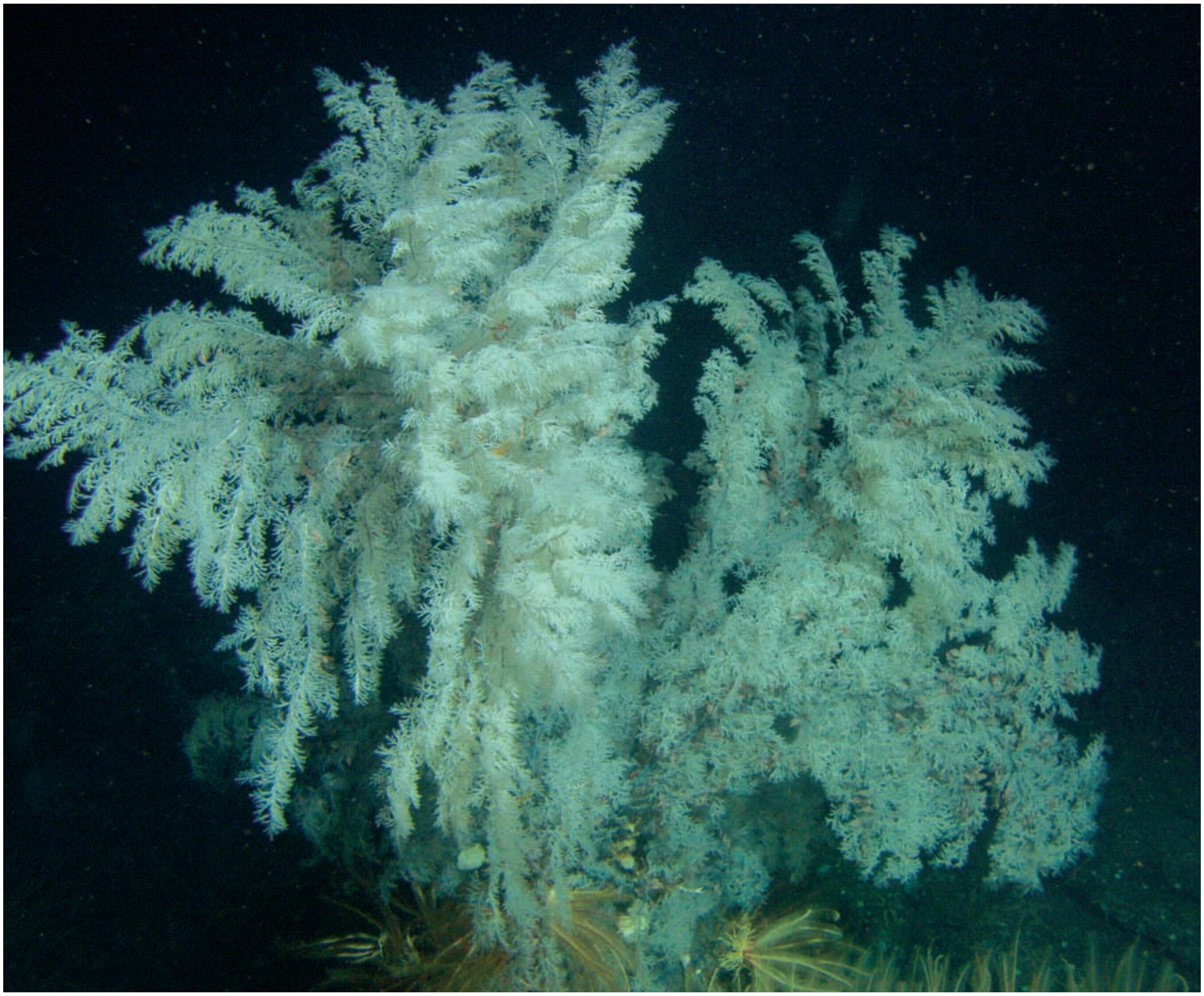

Figure 1.27 Recently discovered Christmas tree coral, *Antipathes dendrochristos*. Photographed from Delta submersible during surveys of deepwater rocky banks off southern California. Photo credit: M. Amend.

(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

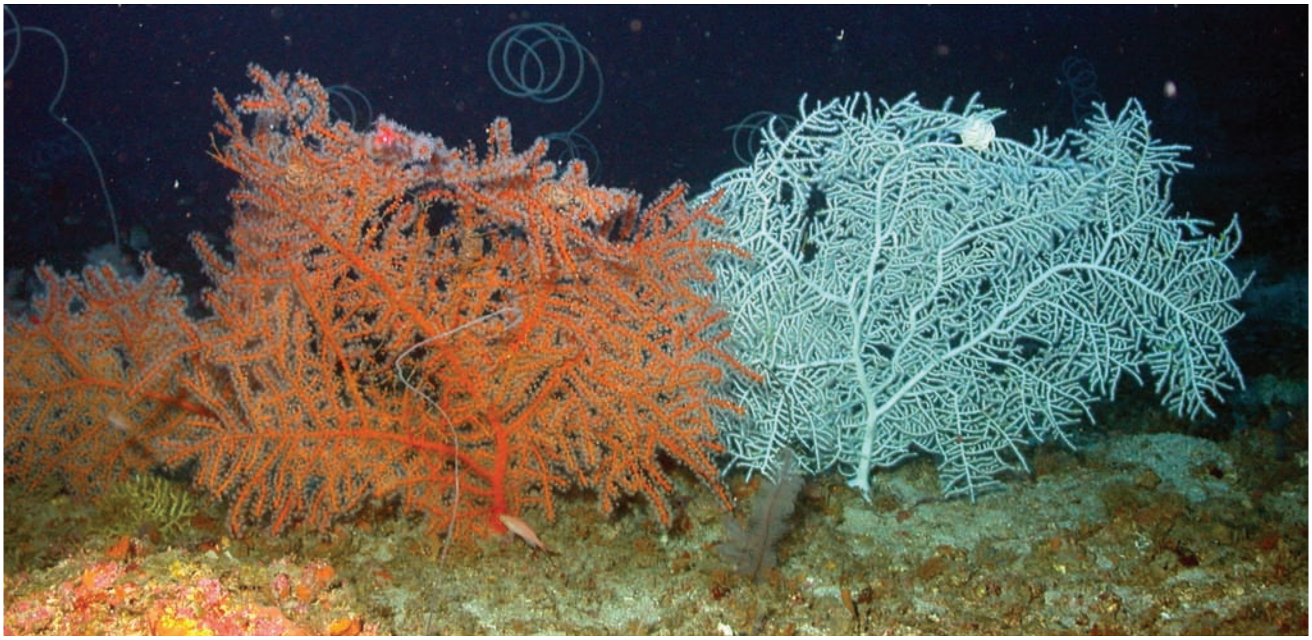

Figure 1.28 Multi-colored gorgonians with whip coral in background. East Bank, Flower Garden Banks NMS Photo credit: NURC/UNCW and NOAA/FGBNMS

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.).

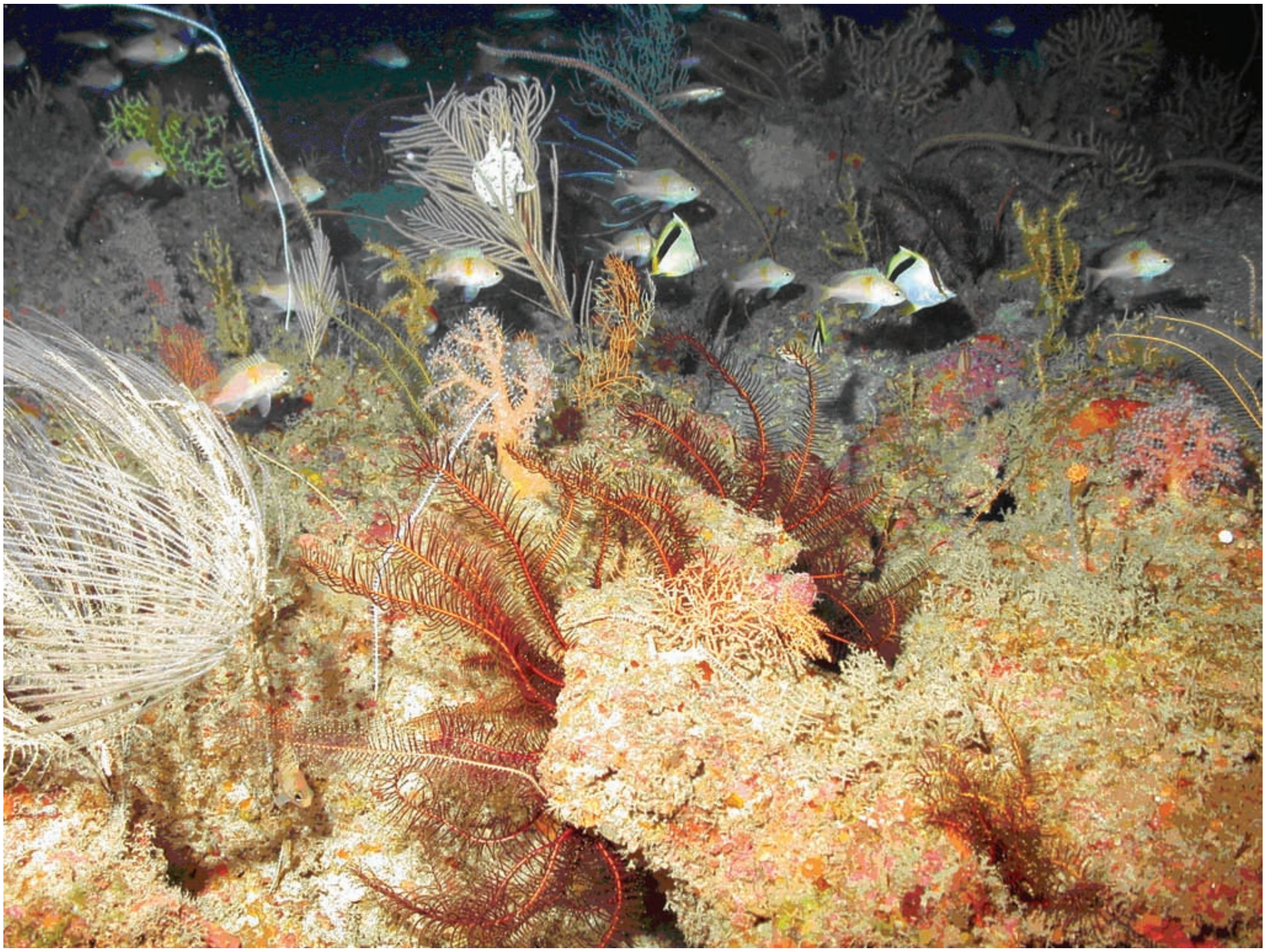

Figure 1.29 An example of deepwater habitat at the Flower Garden Banks NMS, typical of the northwest Gulf of Mexico habitats. Image includes octocorals, antipatharians, echinoderms, sponges, soft corals, and deep-water fishes. Photo credit: FGBNMS and NURC/UNCW.

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.

	Regions						
Threats	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

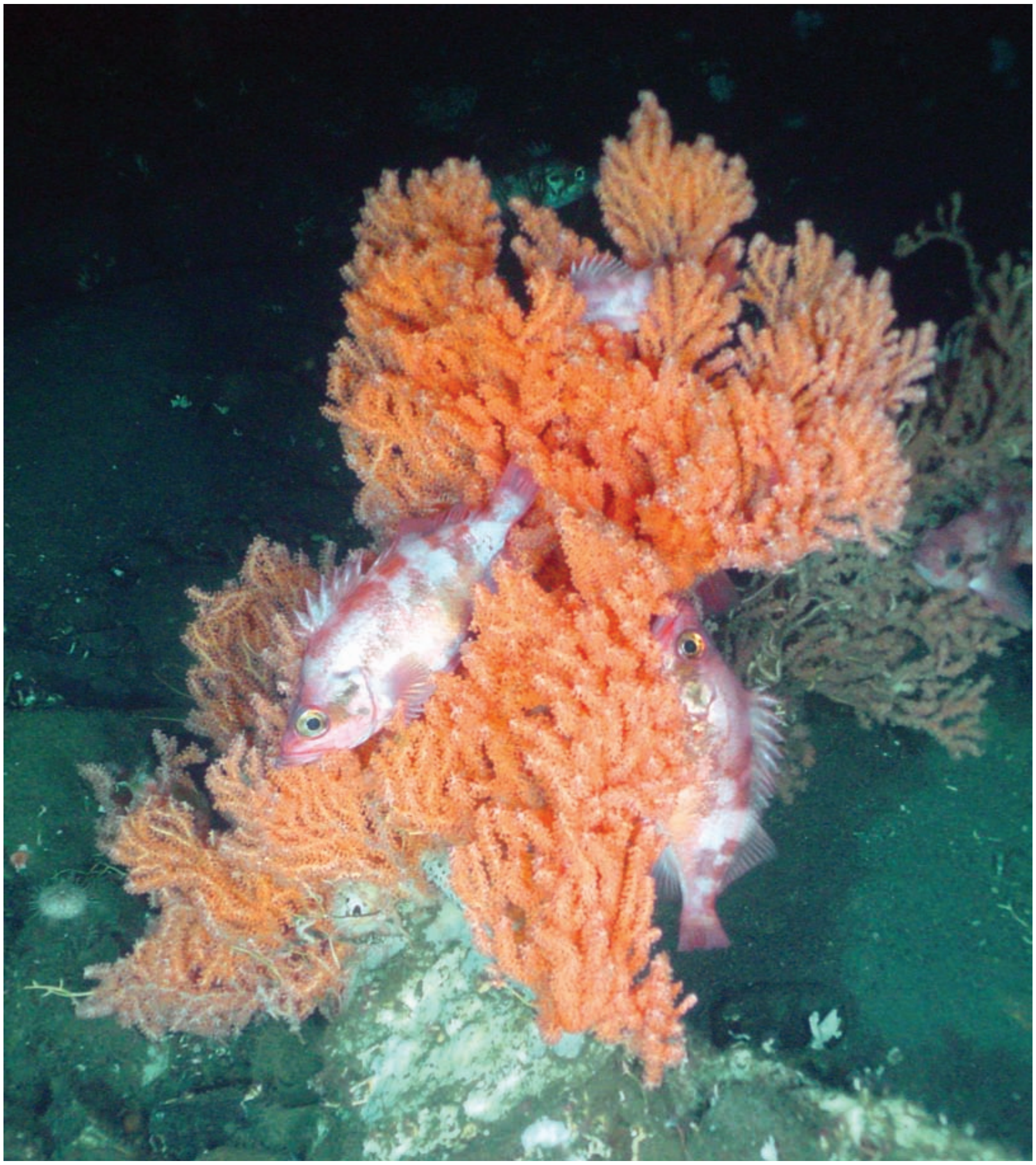

Figure 1.30 Rockfish take refuge among a primnoid octocoral in Olympic Coast National Marine Sanctuary. Photo credt: OCNMS/NOAA

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,

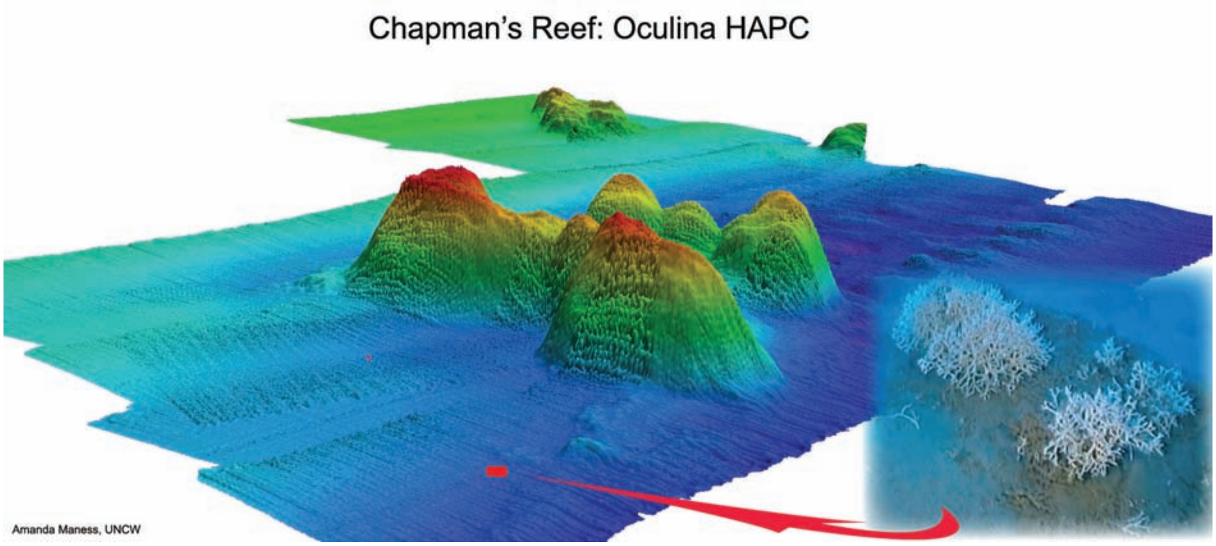

Figure 1.31 3-D colored bathymetry of Chapman's Reef, from 2005 survey done with multibeam sonar from R/V *Cape Fear* by Seafloor Systems, Inc. Image credit: A. Maness.

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	●			