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

Chapter 1 in The State of Deep-Sea Coral and Sponge Ecosystems of the United States Report

Recommended citation: Hourigan TF, Etnoyer PJ, Cairns SD (2017) Introduction to the State of Deep-Sea Coral and Sponge Ecosystems of the United States. In: Hourigan TF, Etnoyer, PJ, Cairns, SD (eds.). The State of Deep-Sea Coral and Sponge Ecosystems of the United States. NOAA Technical Memorandum NMFS-OHC-4, Silver Spring, MD. 38 p.
Available online: http://deepseacoraldata.noaa.gov/library.

Iridogorgia soft coral with squat lobsters in the northwestern Gulf of Mexico. Courtesy of the NOAA Office of Ocean Exploration and Research.

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

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Squat lobster on an Iridogorgia *octocoral in the Johnston Atoll component of the Pacific Remote Islands Marine National Monument.*

I. Introduction

Large, long-lived, sessile organisms contribute structural complexity to seafloor habitats and play an important role in marine ecosystems. In deep or cold oceanic waters, corals and sponges are the most important organisms forming such biogenic habitats (Roberts et al. 2009, Buhl-Mortensen et al. 2010, Hogg et al. 2010, Rossi et al. 2017). They increase the physical heterogeneity of habitat, provide refuge and substrate, increase the number and availability of micro-habitats for other organisms, and thereby create hotspots of biological diversity in the deep sea.

Deep-sea corals, also known as cold-water corals, have become a major focus of new deep-sea research and conservation, both in the United States and worldwide. Recent reviews (Hovland 2008, Roberts et al. 2009, Cordes et al. 2016a) have highlighted the value of the habitats they create and their vulnerability to anthropogenic impacts.

In comparison to deep-sea coral habitats, deep-sea sponge grounds have, until recently, been relatively overlooked and poorly understood (Hogg et al. 2010). This too is beginning to change as new research has highlighted the extent and importance of these habitats (Maldonado et al. 2016).

Deep-sea coral and sponge ecosystems have become a major focus of international conservation efforts. United Nations General Assembly resolutions (UNGA Resolutions 61/105, 64/72, and 66/68) have identified cold-water coral habitats as vulnerable marine ecosystems in need of protection from significant adverse impacts of deep-sea bottom fishing on the high seas. In response, international guidelines on deep-sea fishing (FAO 2009) and conservation actions by Regional Fishery Management Organizations worldwide have focused on protecting coral and sponge habitats as vulnerable marine ecosystems. The Conference of the Parties to the Convention on Biological Diversity (Decision IX/20: CBD 2008) adopted scientific criteria (Annex I to the decision) for identifying ecologically or biologically significant marine areas in need of protection in the open ocean and deep sea. Deep-sea coral and sponge habitats meet the criteria for such designation.

The State of Deep-Sea Coral and Sponge Ecosystems of the United States presents new information gathered over the last decade in the U.S., and summarizes how this information is increasingly being used to inform our nation's ocean resource management. This introduction describes the purpose and purview of the report, and provides a brief summary of national-level activities over the last decade that have supported progress in research, conservation and management.

II. About This Report

In 2007, the United States National Oceanic and Atmospheric Administration (NOAA) published the first peer-reviewed report on the *State of Deep Coral Ecosystems of the United States* (Lumsden et al. 2007; hereinafter referred to as the "2007 Report"). The 2007 Report summarized research on these communities in U.S. waters up to 2006, focusing on the biology and importance of structure-forming deep-sea corals and the communities they support, the threats they face, and their distribution and conservation status in U.S. waters. In the decade since 2007, there has been a tremendous expansion of interest in the science and management of these ecosystems in the U.S. and internationally.

The *State of Deep-Sea Coral and Sponge Ecosystems of the United States* serves as an update to the 2007 Report. It consists of six regional chapters that cover new information on research and efforts to conserve deep-sea coral ecosystems since 2007. The regional chapters also provide the first summary of research on deepwater sponge ecosystems – though for most regions this information is relatively limited. This volume does not include a U.S. Caribbean chapter, as there has been relatively little new information from waters surrounding Puerto Rico, the U.S. Virgin Islands, and Navassa Island since information from that region was last reviewed (Lutz and Ginsburg 2007). Each chapter is accompanied

Figure 1. *The 2017 State of Deep-Sea Coral and Sponge Ecosystems of the United States provides an update to the first NOAA report, State of Deep-Sea Coral Ecosystems of the United States: 2007.*

by an online list of deep-sea coral species known from that region. These independently citable and peer-reviewed lists (including a U.S. Caribbean list) update species inventories contained in the 2007 Report, and substantially increase the number of taxa recorded in U.S. waters. NOAA will work with the taxonomists to update these online deep-sea coral species lists regularly and supplement them with similar species lists for deep-sea sponges.

The 2007 Report contains a large amount of background information on regional ecosystems and management efforts prior to 2007, and the current report is not meant to replace this. Rather, it builds on the 2007 Report, and provides an update on new research and management efforts that have occurred through 2016.

In addition to the regional update chapters, this report includes six spotlight chapters that highlight cross-cutting themes. Each chapter is written by leading experts with an emphasis on how research conducted in the U.S. has contributed globally to our understanding of deep-sea coral species discovery (Cairns et al., Chapter 2), population connectivity (Morrison et al., Chapter 12), predictive modeling (Guinotte et al., Chapter 8), age and growth of deep-sea corals (Prouty et al., Chapter 10), fishing impacts (Rooper et al., Chapter 4), and a case study on managing black coral harvests (Wagner et al., Chapter 6).

III. Corals and Sponges: Key Components of Deep-Sea Biogenic Habitats

Deep-sea corals and sponges occur throughout the world's oceans. Many species attain large sizes and occur in sufficient densities to create habitat for numerous associated organisms, thereby forming the basis for remarkably complex and fragile benthic communities. These habitat-forming or structure-forming species (NOAA 2010) act as "ecosystem engineers" (Jones et al. 2007). Rossi et al. (2017) have dubbed deep-sea coral and sponge habitats "marine animal forests," due to the structural and functional similarities of these communities with terrestrial forests. The three-dimensional features formed by many deep-sea corals and sponges provide habitat for numerous fish and invertebrate species and thereby enhance the biological diversity of many deepwater ecosystems. There is increasing evidence that these habitats may play important ecosystem functions, acting as hotspots of carbon and nutrient recycling in the food-limited deep ocean (Cathalot et al. 2015, Maldonado et al. 2016).

Box 1. Defining Deep-Sea Corals and Sponges

In this report, "deep-sea corals" and "deep-sea sponges" are defined as corals or sponges that do not depend upon symbiotic algae and light for their metabolic requirements, and generally occur at depths below 50 m (NOAA 2010). Deep-sea corals are also referred to as cold-water corals (e.g., Roberts et al. 2009) and were called deep corals in the 2007 Report (Lumsden et al. 2007).

Structure-forming deep-sea corals and sponges are those larger species that provide three-dimensional structure above the seafloor that can be used as habitat by other species. In the case of corals, these include both deep reef-building stony corals (e.g., *Lophelia pertusa*), as well as gorgonians, gold corals, and black corals, which often have branching tree-like forms and either occur singly or occur in aggregations that increase their habitat value. The most important deep-sea structure-forming sponge species are those in the classes Demospongiae and Hexactinellida.

In addition to habitat and ecosystem functions, deep-sea corals and sponges are also valuable to humans in their own right. Cnidarians (predominantly octocorals) and especially sponges are the most important sources of marine natural products (Leal et al. 2012).

Mehbub et al. (2014) reviewed new sponge-derived natural products from 2001 to 2010, which represented about 29% of all marine natural products discovered during this decade. Bath sponges have been harvested for centuries, but now other sponges are being studied for insights into new industrial products ranging from fiber optics (Aizenberg et al. 2005) to nanocrystals (Morse 2007). Black, pink, and red corals are the basis for a large jewelry industry (Wagner et al., this volume).

III.1. Deep-Sea Corals

Deep-sea corals, also referred to as cold-water corals, are a taxonomically and morphologically diverse group of cnidarians distinguished by their predominant occurrence in deep or cold oceanic waters. Cairns (2007) defined corals as "animals in the cnidarian classes Anthozoa and Hydrozoa that produce either calcium carbonate (aragonitic or calcitic) secretions resulting in a continuous skeleton or as numerous, usually microscopic, individual sclerites, or that have a black, horn-like, proteinaceous axis." Table 1 shows the major taxa of deep-sea corals. The anthozoan hexacorals include stony corals (Order Scleractinia), black corals (Order Antipatharia), and several species parazoanthid gold corals (Order Zoantharia – in the genera *Kulamanamana* [formerly *Gerardia*)] and *Savalia*; Sinniger et al. 2013).

The anthozoan octocorals include the true soft corals, stoloniferan corals, gorgonians (Order Alcyonacea), sea pens (Order Pennatulacea), and helioporids (the shallow-water blue coral and the deepwater lithotelestids in the order Helioporacea). Recent molecular phylogenetic studies indicate that the anthozoan subclass Octocorallia is likely monophyletic, but the orders (Alcyonacea, Pennatulacea, and Helioporacea) within the octocorals are likely not (McFadden et al. 2010). Most modern taxonomists treat the large and morphologically diverse soft and gorgonian corals as the single order, Alcyonacea (Daly et al. 2007). Here, as in the 2007 Report, we continue to treat the gorgonians (alcyonaceans with a proteinous and/or calcitic supporting skeletal axis; i.e., species currently included in the suborders: Scleraxonia, Holaxonia, and Calcaxonia) separately from the other alcyonaceans (true soft corals and stoloniferans). We do this for practical reasons (discussed in Hourigan et al. 2007), since many gorgonians are major structure-forming species (in contrast to soft-bodied alcyonaceans, which typically are not), and many surveys report corals as "gorgonians" based on gross morphology when species or family-level identifications are lacking. This practice also allows comparison to the 2007 Report. In the online species lists, however, we have included the gorgonians in the order Alcyonacea in keeping with generally accepted taxonomic reviews (Fabricius and Alderslade 2001, Daly et al. 2007, Watling et al. 2011).

Corals in the class Hydrozoa (sometimes called hydrocorals) are only distantly related to other corals (in class Anthozoa). Most deep-sea species are limited to a single family, Stylasteridae (the stylasterid or lace corals, in the order Anthoathecata). The order Hydrozoa also includes the calcified shallow-water fire corals (Family Milleporidae), and three species of long horn corals, only one of which lives in deep water (Cairns 2007).[1]

Although more than 600 species of scleractinian corals occur deeper than 50m (Cairns 2007), most are solitary corals and only about 20 are considered framework-forming (constructional) species that contribute to deepwater coral reefs or bioherms (Roberts et al. 2009). The six most significant species are *Lophelia pertusa, Solenosmilia variabilis, Goniocorella dumosa, Oculina varicosa, Madrepora oculata*, and *Enallopsammia profunda* (Roberts et al. 2009). In U.S. waters, deep-sea coral bioherms constructed primarily by *O. varicosa, L. pertusa,* and *E. profunda* occur in the Southeast U.S. and by *L. pertusa* in the Gulf of Mexico. Deep-sea coral reefs support faunal communities that are much higher in biomass and diversity than surrounding unstructured deep-sea habitats (Cordes et al. 2008, Roberts et al. 2009, Rossi et al. 2017). Deepwater reefs may also provide an important link between the benthos and diel vertical migrating mesopelagic fishes and macronekton invertebrates (Gartner et al. 2008, Davies et al. 2010).

Since 2007, there has been an increased focus on other types of deep-sea coral habitats, both in the U.S. and internationally. This includes high density aggregations of gorgonians or black corals, often referred to as coral "gardens," and groves of sea pens (Buhl-Mortensen et al. 2010, 2017; Auster et al. 2013; Stone et al. 2005; Stone 2014; De Clippele et al. 2015; Pérez et al. 2016). These have much broader depth and geographic distributions than deep-sea stony coral reefs, and have also been recognized as important biodiversity hotspots in the deep sea (Buhl-Mortensen et al. 2017).

III.2. Deep-Sea Sponges

Sponges are sessile animals in the phylum Porifera, and are among the oldest lineages of animals (Hooper and van Soest 2002). Most species are marine, found from tropical to polar environments and from very shallow to abyssal depths (van Soest et al. 2012). There are four extant classes: Demospongiae (the largest class – sometimes referred to as siliceous and horny sponges), Homoscleromorpha (recently separated from the demosponges), Calcarea (calcareous sponges) and Hexactinellida (glass sponges) (Table 2). The World Porifera Database (Van Soest et al. 2017) lists over 9575 extant species of marine sponges (7,742 Demospongiae, 878 Hexactinellida, 834 Calcarea, and 121 Homoscleromorpha). The phylogeny, systematics, and taxonomy of sponges have recently undergone extensive revisions, and many aspects remain unresolved. The *Systema Porifera* (Hooper and van Soest 2002) represented a major systematic revision of the phylum. This revision was supplemented by recent major revisions to the orders, Homoscleromorpha (Gazave et al. 2010), Demospongiae (Morrow and Cárdenas 2015), and Hexactinellida (Dohrmann et al. 2017).

[1] A few species of other branching deepwater hydrozoans produce chitinous skeletons (e.g., *Hydrodendron gorgonoide*, Order Leptothecata), reach large sizes, and may provide habitat functions similar to many deep-sea corals. While morphologically-similar to gorgonians, these are currently not considered to be corals.

Table 1. *Corals in the phylum Cnidaria that occur in deepwater (> 50 m).*

Class	Subclass	Order	Common Names	Habitat Contribution
Anthozoa	Hexacorallia	Scleractinia	Stony corals	A few branching species form deep-water biogenic reef frameworks known as bioherms, coral banks, or lithoherms. Most deep-sea species are small solitary cup corals.
		Antipatharia	Black corals	Many branching forms, some of which can reach large sizes. Often co-occur with gorgonians.
		Zoantharia	Gold corals	Only a few species in the family Parazoanthidae form rigid skeletons. They parasitize other corals and need other coral hosts to settle on. Gold corals can live for over 2000 years.
	Octocorallia	Alcyonacea	True soft corals and stoloniferan corals	Soft-bodied species. Most are small and although they can occur in significant densities do not appear to be major structure-forming species.
		Gorgonacea (= Alcyonacea, in part)	Gorgonians	Many branching forms that can reach large sizes. A number of species can occur in dense aggregations.
		Pennatulacea	Sea pens	Unlike most other coral orders, sea pens are mostly found on soft sediments, where they can form dense beds that provide important habitat.
		Helioporacea	Lithotelestids	Only three species in one genus are known from deep water. Contribution to habitat is unknown.
Hydrozoa	Hydroidolina	Anthoathecata	Stylasterids or lace corals (Family Stylasteridae)	Can form branching colonies. Most species are relatively small. May be confused with stony corals but the resemblance is superficial.
			Longhorn hydrozoans	Only one species (in the Family Hydractiniidae) of this group is known from deep water. Not an important structure-forming species.

Deep-sea sponges can play ecological roles similar to those of deep-sea corals, creating significant three-dimensional structure on the sea floor that is used by numerous species (Freese and Wing 2003, Bell 2008, NOAA 2010, Buhl-Mortensen 2010, Stone 2014, Hogg et al. 2010, Maldonado et al. 2016). Although they can be found on many different bottom types, most occur on hard substrata (van Soest et al. 2012), also favored by most deep-sea corals. Individual sponges can host a rich complement of microorganisms (Taylor et al. 2007, Webster et al. 2012) and serve as habitat for a variety of larger taxa, including both commensal and obligate symbionts (Klitgaard 1995, Buhl-Mortensen 2010). For example, Sedberry et al. (2004) reported 947 invertebrates representing ten taxonomic groups living in just five individual deepwater sponges of different genera collected in the Southeast U.S. region. Sponge aggregations can range from small patches to dense "sponge grounds" in many deep-sea areas. These deep-sea sponge grounds remain poorly mapped and understood, prompting Hogg et al. (2010) to christen them "Cinderellas of the deep seas."

Demosponge Aggregations: A variety of demosponges can create monospecific or multispecies aggregations. In the Aleutian Islands of Alaska, demosponges greatly outnumber corals and are a primary component of highly diverse coral and sponge gardens (Stone et al. 2011).

Demosponges in the order Tetractinellida (formerly order Astrophorida) can form dense and extensive aggregations (commonly known as astrophorid sponge grounds) on gravel and coarse sand bottoms from 150 – 1,700 m deep in cold temperate and arctic regions (Maldonado et al. 2016). Off Norway, the most abundant sponges on these grounds (e.g., *Geodia barretti*) can reach sizes of 1 m and biomasses as high as 45 kg/m^2 (Kutti et al. 2013). Similar sponge grounds are found along the continental shelf and slopes off Labrador and Newfoundland (Murillo et al. 2012; Knudby et al. 2013; Beazley et al. 2015). Smaller aggregations of tetractinellid sponges are common in the deep sea at lower latitudes. Other unique types of deep-sea demosponge aggregations include "lithistid" sponge grounds and carnivorous sponge grounds (Maldonado et al. 2016).

Glass Sponge Reefs and Aggregations: In the northeast Pacific off British Columbia, glass sponges (class Hexactinellida) in the order Sceptrulophora form unique sponge reefs up to 19 m high and many km long at depths of 90-240 m (Conway et al. 2001, 2005). Smaller glass sponge reefs have recently been documented in Southeast Alaska (Stone et al. 2014, Stone and Rooper, this volume). Elsewhere, glass sponges can form dense, sometimes monospecific, aggregations principally at depths below 300 m (Maldonado et al. 2016). In abyssal depths, small glass sponges are among the few organisms providing refuge for other species (Beaulieu 2001).

Table 2. *Sponges in the phylum Porifera that occur in deep water (> 50 m).*

Class	Subclass	Order	Common Names	Habitat Contribution
Demospongiae	Heteroscleromorpha	*18 Orders*	Demosponges	Demosponges are a large, diverse group. Many species reach large sizes and along with glass sponges represent a major structure-forming taxon in deep water.
	Keratosa	Dendroceratida Dictyoceratida		
	Verongimorpha	Chondrillida Chondrosiida Verongiida		
Hexactinellida	Amphidiscophora	Amphidiscosida	Glass sponges	Glass sponges along with demosponges represent the primary structure-forming deepwater taxa. A few species form large reefs or bioherms in Southeast Alaska and British Columbia.
	Hexasterophora	Hexasterophora incertae sedis Lychniscosida Lyssacinosida Sceptrulophora		
Calcarea	Calcaronea	Baerida Leucosolenida Lithonida	Calcareous sponges	Most calcareous sponges are found in shallow water. A few species occur in deeper water.
	Calcinea	Clathrinida Murrayonida		
Homoscleromorpha	--	Homosclerophorida	--	A small group of mostly encrusting forms in deep water.

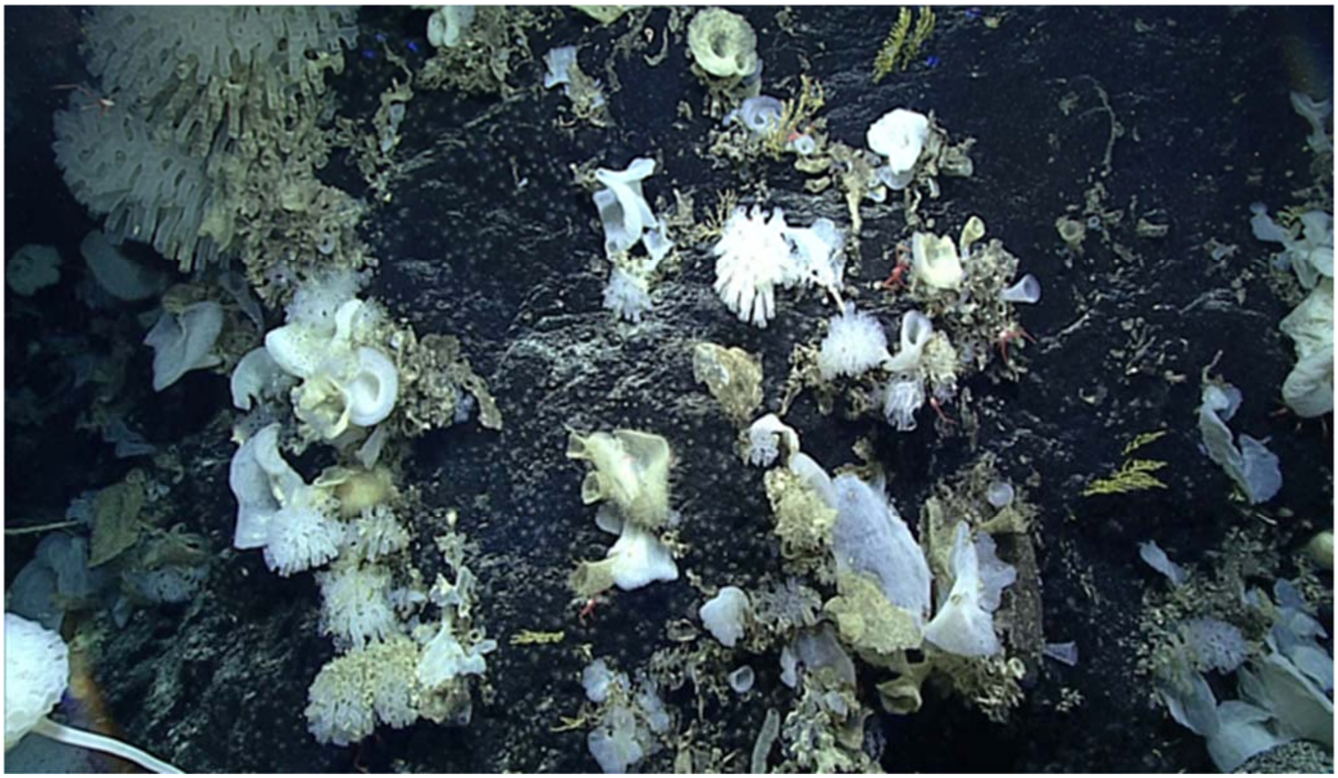


Figure 2. *Dense community of glass sponges on Pioneer Seamount in the Northwestern Hawaiian Islands.*

Dense aggregations of filter-feeding deep-sea sponges may also play an important ecosystem function in nutrient and biogeochemical cycles. They filter large amounts of water and can convert dissolved organic matter into particulate organic matter, which in turn is used by other organisms (Maldonado et al. 2016). In this way, sponges may play an important role in carbon, nitrogen, and silicate cycling and enhancing local productivity.

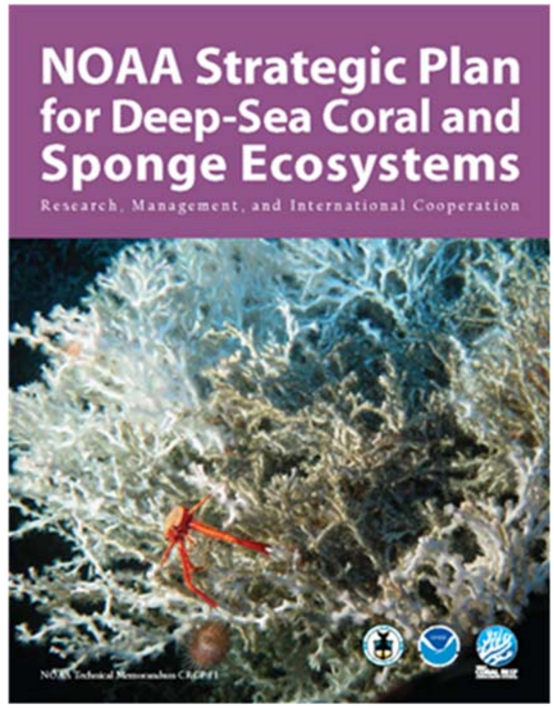
There is international recognition that deep-sea sponge grounds represent vulnerable habitats. Deep-sea sponges have been recognized as a key component of vulnerable marine ecosystems (FAO 2009) and create habitats that meet the criteria for Ecologically and Biologically Significant Areas in the deep sea (Hogg et al. 2010). Deep-sea sponge ecosystems also face many of the same threats as deep-sea corals – particularly damage from bottom trawling (Freese et al. 1999, Freese 2003, Wassenberg et al. 2002, Hogg 2010, Stone and Rooper, this volume). Deep-sea sponge aggregations are a habitat type listed on the OSPAR list of Threatened and/or Declining Species and Habitats (OSPAR 2008). This recognition led NOAA to include deep-sea sponges in its 2010 *Strategic Plan for Deep-Sea Coral and Sponge Ecosystems* (see below and Box 2).

IV. U.S. National Overview

IV.1. A Strategic Approach

The National Oceanic and Atmospheric Administration (NOAA) is the lead federal agency mandated to conserve and manage the nation's marine resources, including deep-sea coral and sponge ecosystems. In 2010, NOAA published a *Strategic Plan for Deep-Sea Coral and Sponge Ecosystems: Research, Management, and International Cooperation* (NOAA 2010, Box 2). The plan identifies goals, objectives, and approaches to guide NOAA's research, management, and international cooperation activities on deep-sea coral and sponge ecosystems.

Of particular consequence was the Strategic Plan's approach to managing bottom-fishing impacts to deep-sea coral and sponge habitats. Bottom-contact fishing gears, especially bottom trawls, currently present the most important and widespread threat to deep-sea coral and sponge habitats, both worldwide (Roberts et al. 2009, Hogg et al. 2010, Ragnarsson et al. 2017) and within many U.S. regions (Hourigan et al. 2007, Rooper et al., this volume). Because NOAA's National Marine Fisheries Service (NMFS), in partnership with the regional Fishery Management Councils, is the federal agency responsible for managing fisheries in the U.S. exclusive economic zone (EEZ) where most deep-sea corals and sponges occur, managing fishing threats to these ecosystems is a primary focus of the Strategic Plan.



Box 2. Strategic Plan

NOAA's *2010 Strategic Plan* guides the agency's objectives and approaches in three areas related to deep-sea coral and sponge ecosystems:

1. **Exploration and Research** –provides decision-makers with scientific information to enable effective ecosystem-based management.
2. **Conservation and Management** – guides NOAA efforts to enhance protection of these ecosystems, working with the Regional Fishery Management Councils, other Federal agencies and partners. NOAA's strategy is based on authorities provided through the Magnuson-Stevens Fishery Conservation and Management Act (MSA) and the National Marine Sanctuaries Act.
3. **International Cooperation** – describes NOAA's participation in international activities to study and conserve vulnerable deep-sea coral and sponge ecosystems.

The NOAA Strategic Plan supports area-based (i.e., spatially-explicit) protection of identified areas of high density structure-forming deep-sea corals or sponges, and recommends a precautionary approach to prevent expansion of the most damaging fishing activities into unsurveyed areas that might contain deepwater corals, sponges, and other vulnerable biogenic habitats (Hourigan 2014). This approach formed the basis of the historic protection measures proposed by the Mid-Atlantic Fishery Management Council and instituted by NOAA in 2016 (see Packer et al., this volume). The Strategic Plan also highlighted the importance of measuring and addressing fisheries bycatch of deep-sea corals and sponges. The NMFS *National Bycatch Reduction Strategy* (NMFS 2016a) calls upon the agency to: (1) identify areas of high bycatch of deep-sea corals and sponges; (2) to work with regional Fishery Management Councils and the fishing industry to close these areas to high-bycatch gears as called for in the *Strategic Plan for Deep-Sea Coral and Sponge Ecosystems*; and (3) to collect better data on coral bycatch and post-interaction mortality. The agency's most recent U.S. National Bycatch Report (NMFS 2016b) contains quantitative information on the bycatch of deep-sea corals and sponges off the West Coast and Alaska.

Within the U.S. government, interest in these deepwater ecosystems is not limited to NOAA. The U.S. Geological Survey (USGS) released *Strategic Science for Coral Ecosystems 2007-2011* (USGS 2007), which described the information needs of resource managers for both shallow and deep coral ecosystems and summarized research conducted by USGS scientists and partners. The agency-shared long-term vision is to develop a more complete understanding of the physical, chemical, and biological processes – both natural and anthropogenic – that control or influence the structure, function, and ecological relationships within coral communities.

IV.2. Research Advances Understanding

IV.2.i – Deep-sea science spurred by advances in technology

Research on U.S. deep-sea coral and sponge ecosystems has benefited from the availability of new tools and techniques (Fig. 3). In 2008, NOAA commissioned the *Okeanos Explorer* to systematically explore our largely unknown ocean for the purpose of discovery and the advancement of knowledge. Telepresence uses satellite communications to allow scientists from around the world to participate in expeditions remotely by connecting the ship and its discoveries live with audiences ashore. The NOAA Ship *Okeanos Explorer* is joined by the Ocean Exploration Trust's E/V *Nautilus*, also equipped with telepresence capabilities, and a new generation of NOAA fisheries research vessels conducting deep-sea coral and sponge research in U.S. waters. These and other vessels have begun to map the seafloor more systematically, and at higher resolution, using multibeam sonar. Meanwhile, improvements to remotely-operated vehicles (ROVs), autonomous underwater vehicles (AUVs) and other equipment (Fig. 3) have provided for more detailed surveys, revealing previously

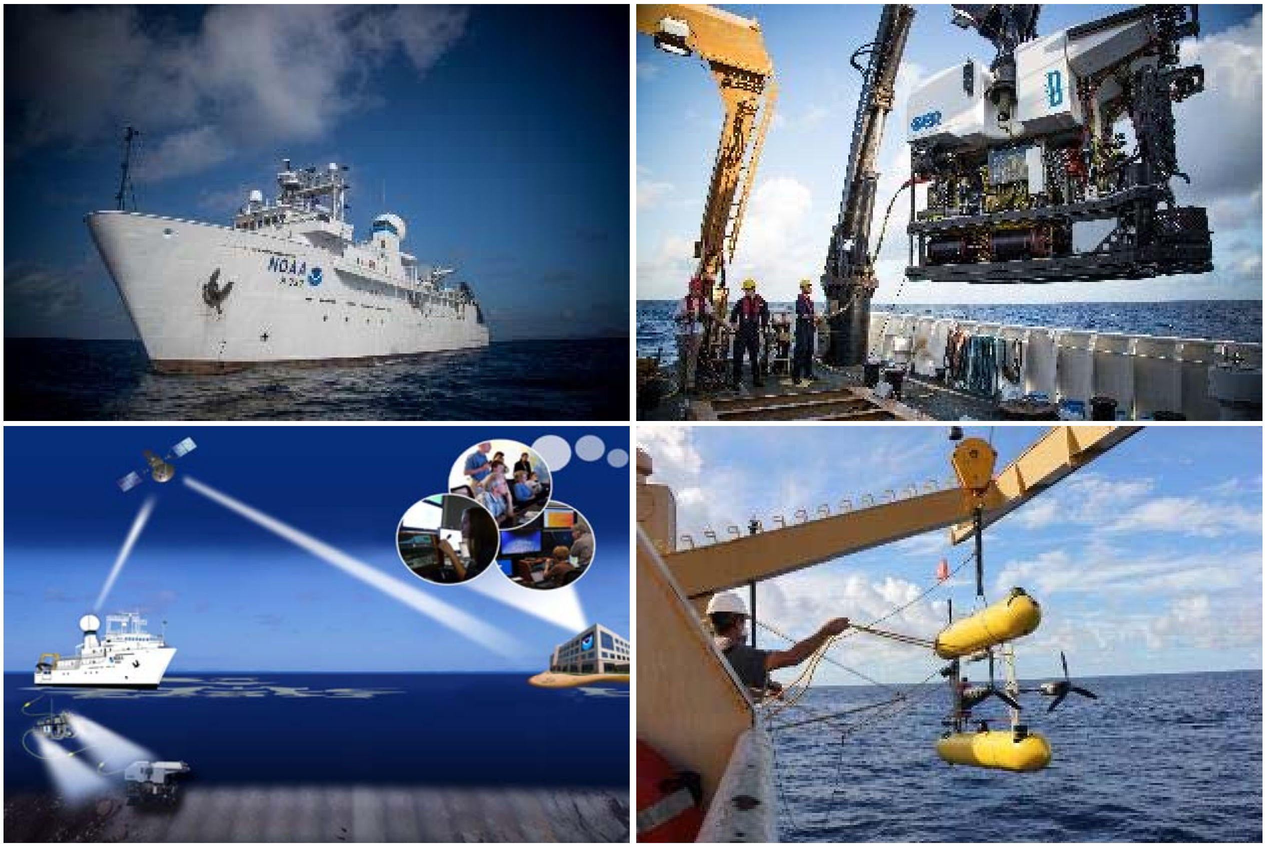


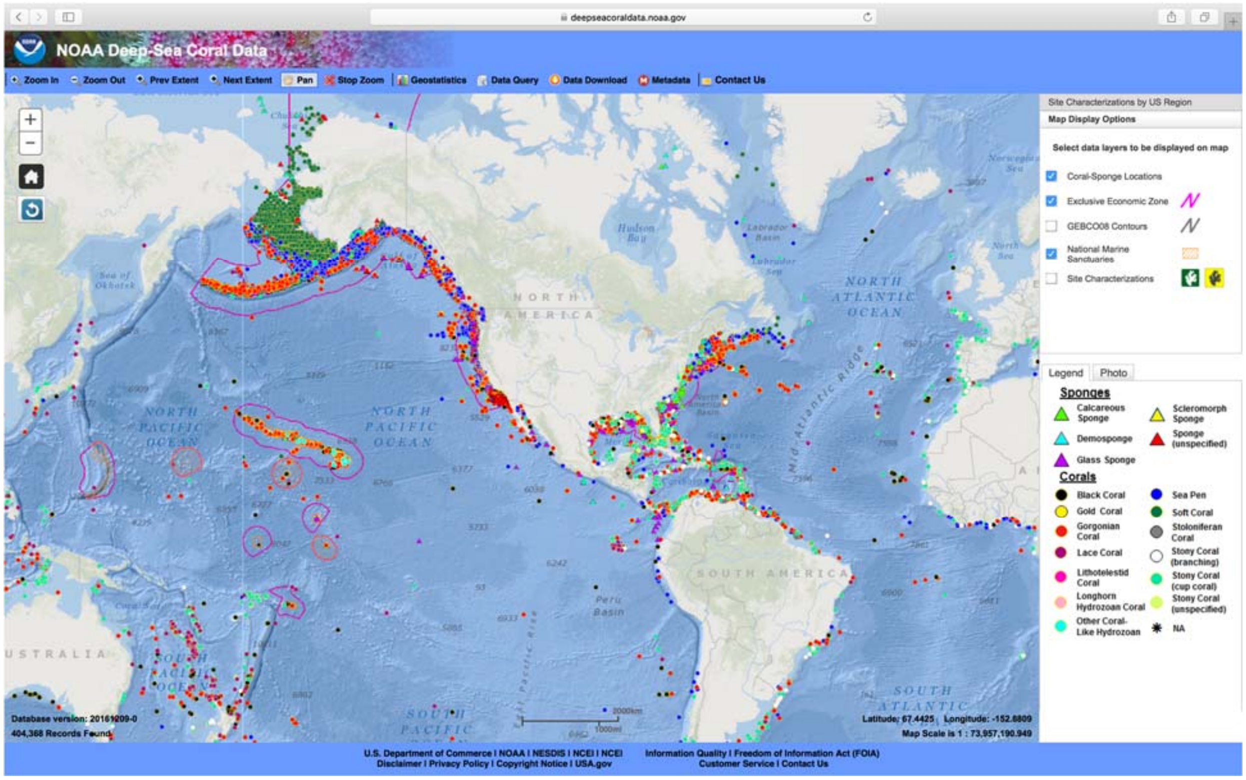
Figure 3. *Advanced Technology used to explore and understand deep-sea coral and sponge ecosystems: a) NOAA Ship* Okeanos Explorer*; b) Deep Discoverer ROV; c) Telepresence-enabled exploration; d) SeaBed AUV.*

unknown habitats to depths of 6000 m.

In addition to new survey technologies, understanding of these ecosystems has benefitted from a host of other new approaches. As reviewed by Cairns et al. (this volume), new genetic techniques have revolutionized our understanding of taxonomy and systematics, and are being applied for the first time to understanding the connectivity of deep-sea coral and sponge populations (e.g., Morrison et al., this volume). Predictive modeling of deep-sea coral habitats has advanced considerably, and is helping target both new research and conservation efforts (Guinotte et al., this volume). Other new techniques allow corals to tell the history of past oceanographic conditions they have experienced (Prouty et al., this volume), and reveal the remarkable microbial associates of deep-sea corals (e.g., Kellogg et al. 2016) and sponges. Sponges, in particular, host exceptionally dense and diverse microbial communities (reviewed by Taylor et al. 2007, Webster et al. 2012, Thomas et al. 2016).

IV.2.ii – NOAA's Deep Sea Coral Research and Technology Program

NOAA's Deep Sea Coral Research and Technology Program is the only U.S. national program dedicated to research on deep-sea coral ecosystems. It was established in the 2007



Box 3. National Database for Deep-Sea Corals and Sponges (https://deepseacoraldata.noaa.gov)

NOAA's Deep Sea Coral Research and Technology Program has compiled a database of the known locations of deep-sea corals and sponges, beginning in U.S. waters (Hourigan et al. 2015). Representing the most comprehensive collection of deep-sea coral and sponge records and information for U.S. waters, the database is available publicly in NOAA's Deep-Sea Coral Data Portal. The portal includes a digital map displaying more than 500,000 records. The National Database includes records from samples archived in museums and research institutions, reported in the scientific literature, as well as observations collected during deep-water surveys conducted by NOAA and other research institutions.

In addition to showing locations of corals and sponges, the fully searchable map also provides access to the following:

- In situ photos of the organisms.
- Extensive associated data available for download about coral and sponge observations, including record provenance, details about where and how they were observed or collected, and, where available, ecologically important information, such as their density, size, and habitat.
- Reports that characterize the deep-sea coral and sponge habitats surveyed over the past decade by scientists from NOAA, other agencies, and universities.
- Deep-sea coral habitat suitability model layers.

The National Database for Deep-Sea Corals and Sponges is continually expanding, incorporating new records from recent fieldwork observations and historic archives quarterly. Additional software tools for data exploration and analysis are under development. The Portal also offers information about studies funded by the Deep Sea Coral Research and Technology Program since 2009 and a growing library of NOAA publications on deep-sea corals and sponges.

reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act (MSA, Section 408), the nation's primary fisheries management legislation. The mission of the program is to provide the science needed to conserve and manage vulnerable deepwater ecosystems. While focused on deep-sea corals, NOAA has informed congress and the public that the program will also collect complementary information, if available, on high biodiversity deep-sea sponge habitats (NMFS 2008).

The Deep Sea Coral Research and Technology Program began operations in 2009. It has conducted 3-4 year field research initiatives in nearly all U.S. regions, as outlined in the regional chapters that follow. Surveys conducted by the program and its partners have supported management efforts across the country, including identification of vulnerable coral and sponge habitats to be protected from damaging bottom-fishing gears, expansion of National Marine Sanctuaries and Monuments, and the establishment of the Northeast Canyons and Seamounts Marine National Monument.

These field initiatives have been supplemented by targeted projects to map deep-sea coral distributions, model predicted deep-sea coral habitat (Guinotte et al., this volume), study coral genetics and connectivity (e.g., Everett et al. 2016), and support coral bycatch reduction. Data collected by the Deep Sea Coral Research and Technology Program and its partners contribute to NOAA's National Database for Deep-Sea Corals and Sponges (Box 3, Hourigan et al. 2015) and are available through the program's map portal (www.deepseacoraldata.noaa.gov).

IV.2.iii – Other major research programs

The last decade also saw the results from major U.S. interagency collaborations focused on deep-sea coral ecosystems led by the Department of Interior's Bureau of Ocean Energy Management (BOEM, formerly Minerals Management Service), in collaboration with the U.S. Geological Survey (USGS) and NOAA, and sponsored by the National Oceanographic Partnership Program (NOPP). As described by Boland et al. (this volume), major multidisciplinary studies were conducted in the Gulf of Mexico during the 2004-2006 (*Lophelia I*; Sulak et al. 2008), 2005-2009 (*Chemo III*; Brooks et al. 2014) and 2008-2012 (*Lophelia II*; Brooks et al. 2016). These studies, particularly *Lophelia II*, produced unprecedented new information on the biology and life history of major structure-forming corals (*Lophelia pertusa*, the black coral *Leiopathes* sp., and the gorgonian *Callogorgia* spp.), community structure, trophic relationships, and other aspects of these deep-sea coral communities (Brooks et al. 2016). A similar collaboration was conducted in the Mid-Atlantic's Baltimore and Norfolk Canyons (Packer et al., this volume).

IV.3. Conservation Status of U.S. Deep-Sea Coral and Sponge Ecosystems

Understanding the conservation status of deep-sea coral and sponge ecosystems requires information on the following topics: (1) the spatial distribution of these biogenic habitats; (2) the spatial extent and intensity of anthropogenic activities that pose potential threats and their overlap with biogenic habitats; (3) the sensitivity of these ecosystems to different impacts and their recovery potential; and (4) the effectiveness of management measures to address these threats (Ragnarsson et al. 2016). There has been substantial progress over the last ten years on each of these fronts in regard to deep-sea coral and sponge ecosystems.

IV.3.i – Spatial distribution of U.S. deep-sea corals and sponges

Deep-sea habitats are difficult and expensive to survey. The United States has the world's second largest exclusive economic zone (EEZ), most of it below the edge of the continental shelf (i.e., greater than ~200 m deep). This area remains largely unmapped, and the areas visually surveyed for deep-sea corals or sponges are miniscule. Nevertheless, the last decade has seen a more systematic approach to both mapping the seafloor and understanding the distribution of deep-sea habitats. This information has been identified as the first priority nationally for management (Hourigan 2014, regional chapters in this Report).

Deep-Sea Coral Distributions: Structure-forming corals are widespread in deeper waters of all regions except the U.S. Arctic. Although largely unexplored, only sea pens and one soft coral (*Gersemia* sp.) have been reported from the Chukchi Sea and Beaufort Seas (Stone and Rooper, this volume). This result contrasts to the Arctic north of the Atlantic, where extensive and relatively diverse coral habitats have been discovered off Canada, Greenland, and Norway (Roberts et al. 2009). NOAA's National Database for Deep-Sea Corals and Sponges (Box 3) has resulted in the first comprehensive maps of coral presence in areas of U.S. waters that have been sampled (map annexes in each regional chapter). Predictive habitat models allow some extrapolation of these data to unsurveyed areas (Guinotte et al., this volume). Such maps and models of coral presence, however, do not yet capture the local extent of habitats nor the density and diversity of corals within the habitats – features that are most important for determining their conservation value.

Although deep-sea corals occur widely, areas of high-density aggregations (e.g., coral "gardens") are highly localized, and may be small (many on the scale of tens to hundreds of meters across). They therefore represent a comparatively rare habitat type. Yet these coral garden areas support diverse communities of other organisms and represent hotspots of biological diversity in the deep sea (e.g., Auster et al. 2013, Stone 2014). Their diversity and rarity makes them both extremely valuable and extremely vulnerable.

The only true deepwater stony coral reefs (bioherms) have been observed in the U.S. Southeast (Hourigan et al., this volume) and Gulf of Mexico (Boland et al., this volume), and most recently on seamounts of the Northwestern Hawaiian Islands and Emperor Seamount Chain (Baco et al. 2017). Some deep-sea reef formations may also occur in unsurveyed areas of the U.S. Caribbean. U.S. deepwater coral reefs are most diverse and numerous in the Southeast, where they probably rank among the most extensive deep-sea coral reef provinces in the world. These reefs, along with coral and sponge gardens in the Aleutian Islands, represent the largest extents of highly diverse U.S. deep-sea coral communities. However, every U.S. region contains truly remarkable habitats, often in areas of clear water – on ridges, seamounts, canyon walls and shelf-edge breaks – where there is hard substratum, sufficient food, and moderate to strong currents.

New explorations continue to reveal amazing new habitats. Deep-sea surveys in the U.S. Pacific Island Territories began in 2016 (too recent to be reflected in the U.S. Pacific Islands summary; Parrish et al., this volume), revealing extensive and dense coral and sponge gardens on ridges and seamounts. New research has also uncovered unexpectedly rich habitat areas within the current bottom-fishing footprint that appear to have escaped damage (e.g., coral gardens in the Gulf of Maine, Northern California, and Aleutian Islands). These areas represent conservation priorities, as they face the most immediate threats from bottom-fishing.

Deep-Sea Sponge Distributions: The Gulf of Mexico (Rützler et al. 2009) and the Aleutian Islands in Alaska (Stone et al. 2011) are the only regions with moderately systematic lists of deep-sea sponge species, although species lists exist for certain sub-areas (e.g., California, Lee et al. 2007). Mapping of sponge distributions has barely begun, and with the exception of some Alaskan areas (Rooper et al. 2014, Rooper et al. 2016), no predictive habitat models have been developed to date. The most comprehensive picture of sponge presence comes from scientific trawl surveys conducted off Alaska and the U.S. West Coast (Clarke et al., this volume) – though most records are only recorded as "Porifera," and the surveys cannot access areas of rough topography that may be especially important habitats for many species. These surveys indicate that certain areas have high bycatch of sponges and likely represent high-density sponge grounds. These include monospecific sponge grounds in Alaska's Bristol Bay (B. Stone pers. comm.), and highly diverse sponge gardens in the Aleutian Islands that have also been visually surveyed (Stone 2014, Goddard et al. 2017). Bycatch of sponges from commercial fisheries off the U.S. West Coast and Alaska is an order of magnitude larger by weight than the bycatch of corals, and the Alaska sponge bycatch is 50 to 100 times higher than off the West Coast. This trend supports the generalization that high-density deep-sea sponge grounds are more common in cold temperate waters (Maldonado et al. 2016).

Pile and Young (2006) reported that the deep-sea glass sponge, *Sericolophus hawaiicus*, forms dense beds (mean density: 4.7/m^2) over

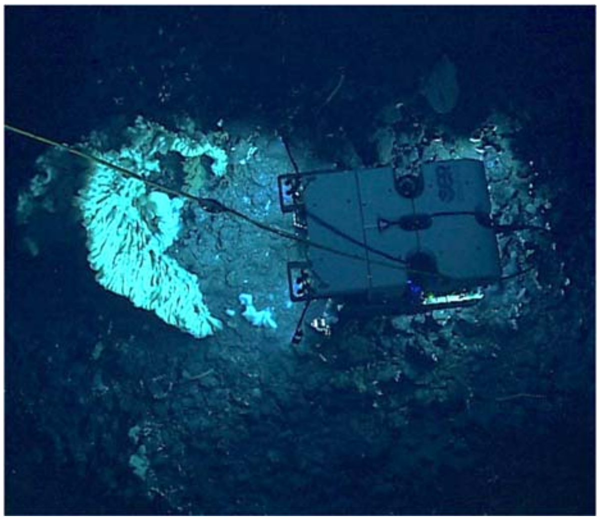


Figure 4. *Massive glass sponge discovered at a depth of 2117 m in the Northwestern Hawaiian Islands. The picture shows the sponge and the ROV Deep Discoverer. The sponge was estimated to be over 3.5 m in length, 2.0 m in width and 1.5 m in height, making it the largest sponge recorded to date.*

extensive areas at depths between 360 – 460 m off the Big Island of Hawaii. Unlike many deep-sea sponges that occur only on hard substrata, *S. hawaiicus* is adapted to anchor in the sand. Recent explorations in both the Hawaiian Archipelago and other U.S. Pacific Islands and seamounts have revealed dense aggregations of glass sponges on rocky ridges. These explorations included the discovery of what may be the largest sponge ever reported (Wagner and Kelley 2016; Fig. 4).

There have been no systematic surveys of deep-sea sponge habitats in other U.S. regions. Our understanding of these ecosystems has been hampered by lack of appreciation of their importance, and by limited U.S. expertise in taxonomy and ecology of deepwater sponges.

IV.3.ii – Anthropogenic threats

The 2007 Report summarized information on anthropogenic threats to deep-sea coral ecosystems in U.S. regions (Hourigan et al. 2007). Bottom trawl fisheries were the most serious threat in Alaska, the U.S. West Coast, Northeast, and Southeast regions. Other bottom-tending gear, including traps, bottom-set longlines, and gillnets can also damage deep-sea corals (Baer et al. 2010, Sampaio et al. 2012, Rooper et al., this volume). These gears may be used preferentially in steep and rocky habitats (i.e., areas of high rugosity) that are inaccessible for trawling, thereby representing the primary fishing gear damaging corals and sponges in such areas. Oil and gas development was considered a moderate threat in the Gulf of Mexico, and invasive species and precious coral harvests were of particular concern in Hawaii. Other threats, while possibly significant at a local level, had relatively small footprints compared to bottom fishing. At the time, there was insufficient information on potential impacts of climate change to these ecosystems to assign a threat level.

The last decade has seen an increase in awareness of potential threats to deep-sea ecosystems (Ramirez-Llodra et al. 2011, Mengerink et al. 2014, Koslow et al. 2016). Ramirez-Llodra et al. (2011) concluded that impacts to the deep sea were increasing globally, with deep-sea coral habitats among the most vulnerable, and fishing, especially bottom trawling, being their most serious current threat. Climate-related changes, including ocean acidification, ocean warming, and changes in deep-sea current regimes and productivity were expected to become major threats in the future. This general conclusion based on scientific expert opinion is supported by recent reviews of threats to deep-sea coral ecosystems by other authors (Roberts et al. 2009, Cordes et al. 2016a, Koslow et al. 2016, Ragnarsson et al. 2017), each of which highlighted vulnerability to threats from fishing, fossil fuel exploitation, climate change, and ocean acidification. Reviews of impacts to deep-sea sponge ecosystems have also identified bottom-trawling as the most serious current impact (Hogg et al. 2010, Maldonado et al. 2016).

Table 3 provides an updated summary of anthropogenic threats to deep-sea corals and sponges in U.S. regions based on published literature and expert judgement (reviewed in the regional Chapters), and compares these to threats described in the 2007 Report. We assume that impacts to sponges from physical disturbances are qualitatively similar to impacts to corals from the same activities (e.g., Stone 2014). The following represent the major changes to the 2007 threat assessment:

Bottom Fishing: Damage from bottom trawling is still considered the biggest threat to deep-sea coral and sponge ecosystems where it occurs in U.S. regions where these gears are used (Alaska, U.S. West Coast, Northeast U.S.). Bottom trawling in the Southeast U.S. and Gulf of Mexico is restricted to a small number of vessels engaged in deepwater shrimp fisheries. There is still incomplete information on the footprint of bottom-fisheries in the U.S., but information has improved in certain areas (e.g., the West Coast; see Clarke et al., this volume). In a series of National Bycatch Reports (NMFS 2011, 2013, 2016b), NOAA quantified the bycatch of corals and sponges by fishery in Alaska (2003-2005; 2010-2013) and the U.S. West Coast (2011-2013). There continues to be significant bycatch of corals and sponges – primarily from a limited number of trawl fisheries and from relatively discrete locations within these large regions. The highest rates by far are from the rockfish trawl fishery in the Aleutian Islands. As noted by Rooper et al. (this volume), fixed gears (e.g., bottom-set longlines, gillnets, and traps) can also damage deep-sea corals and sponges, but less is known about the extent of their impacts. Their footprint is certainly orders of magnitude smaller than that of trawling, but may allow targeting of prime coral or sponge habitats that are unsuitable for trawling. Steps taken by the South Atlantic and Mid-Atlantic Fishery Management Councils have significantly increased the area of protected deep-sea coral and sponge habitats, reducing the threat from bottom-fishing impacts to the most important areas.

Oil and Gas Development: The potential impacts of oil and gas development came into stark focus with the Deepwater Horizon oil spill (Boland et al., this volume). Deep-sea coral habitats at three sites from 6-22 km away from the wellhead (White et al. 2012, Fisher et al. 2014a, Fisher et al. 2014b) were damaged by the oil spill – evidently as a result of a deepwater plume. Gorgonians at mesophotic depths (60–88 m) in areas below the surface oil slick also exhibited significant declines in condition

Table 3. *Summary of perceived levels of threats (based on Lumsden et al. 2007 and chapters within this report) to deep-sea coral communities (2007 and 2017) and sponge communities (2017) for U.S. regions. NA = Not Applicable (i.e., this threat is prohibited or does not occur anywhere within the region).*

Note: *Perceived threat levels reflect only the occurrence of these stressors in a region and their potential, if unmitigated, to damage deep-sea coral and sponge communities. They do not indicate the actual impacts of each stressor, which can vary widely within and among regions. Since the location of deep-sea coral and sponge habitats is incompletely known, there is uncertainty over their degree of overlap with human activities. The U.S. has taken substantial management steps to mitigate many threats, and the change in perceived threats for fishing in the Northeast and Southeast reflect recent protections. The 2007 Report did not separate ocean acidification from climate change, and deep-sea mining was not analyzed as a potential threat.*

THREATS	U.S. REGIONS													
	Alaska		West Coast		Pacific Islands		Northeast		Southeast		Gulf of Mexico		Caribbean	
	2007	2017	2007	2017	2007	2017	2007	2017	2007	2017	2007	2017	2007	2017
Bottom Trawl Fishing Impacts	High	High	High	High	NA	NA	High	Medium	High	Medium	Low - Medium	Low - Medium	NA	NA
Other Bottom Fishing Impacts	Low - Medium	Medium	Low - Medium	Low - Medium	Low	Low	Low - Medium	Low - Medium	Low - Medium	Low - Medium	Low - Medium	Low - Medium	Low	Low
Deep-Sea Coral Harvest	NA	NA	NA	NA	Medium	Medium	NA	NA	NA	NA	NA	NA	NA	NA
Oil & Gas Development	Low	Low	Low	Low	NA	NA	NA	Low	NA	Low	Medium	Medium	NA	NA
Cable Deployment	Low	Low	Low	Low	Unknown	Low	Low	Low	Low	Low	Low	Low	Unknown	Low
Sand and Gravel Mining	Low	Low	NA	NA	NA	NA	Low	Low	Low	Low	Low	Low	NA	NA
Deep-Sea Mining		Low		Low		Low - Medium		Low		Low		Low		Low
Invasive Species	Unknown	Unknown	Unknown	Unknown	Medium	Medium	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Climate Change	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Ocean Acidification		Medium		Medium		Medium		Low		Low - Medium		Low - Medium		

(Etnoyer et al. 2016, Silva et al. 2016). Cordes et al. (2016b) recently reviewed the environmental impacts of the oil and gas industry: when potential accidental spills are taken into account, the potential threat posed by oil and gas development in the Gulf of Mexico to deep-sea coral ecosystems is greater than originally supposed by Hourigan et al. (2007). The Deepwater Horizon oil spill was a rare, worst-case scenario, and greatly improved measures have been put in place to prevent this kind of spill from happening again. During the last decade, offshore oil and gas exploration and leasing has been considered for additional regions, including Alaska (Stone and Rooper, this volume) and the Mid-Atlantic (Packer et al., this volume). While active fossil fuel development in these regions is currently on hold, the increased possibility of this moving forward in the future is reflected in Table 3.

Renewable Energy: Offshore renewable energy, especially offshore wind energy, has recently become a major driver for more comprehensive ocean planning in a number of regions. The nation's first offshore wind installation began operations off Rhode Island in 2016 (Packer et al., this volume). Most offshore wind facilities are expected to be sited on the continental shelf relatively close to shore, and thus are less likely to impact major deep-sea coral and sponge habitats. There is, however, the potential for anchored wind turbines in deepwater areas nearshore (e.g., in Hawaii), which could affect deep-sea coral and sponge habitats. Developers have also proposed potential marine current energy off southeastern Florida (Vinick et al. 2012) and ocean thermal energy conversion projects off Hawaii and southeastern Florida that could damage deepwater biogenic habitats. Any proposed activities would result in site-specific surveys conducted to avoid impacts from installations.

Deep-Sea Mining: There are currently no proposals for deep-sea mining within U.S. waters. Nevertheless, there is increasing interest and capacity for deep-sea mining worldwide. Deep-sea mineral resources contain commercially important quantities of high-grade ores increasingly valued in modern technology (Hein 2010, Hein et al. 2013). The principal deep-sea mineral resources being considered for mining include the following:

- Polymetallic manganese nodules, generally occurring at abyssal depths (3,500 – 6,000 m).
- Seafloor massive sulfides, also known as polymetallic sulfides, associated with active or extinct hydrothermal vents.
- Cobalt manganese crusts on seamounts. The prime crustal zone occurs in the North Pacific, including areas around Hawaii and U.S. Pacific territories.
- Phosphorite nodules, typically found between 200-400 m depth.

Mining, if it occurs, is likely to completely destroy deep-sea coral or sponge habitats within its footprint (Ramirez-Llodra et al. 2011, Levin et al. 2016). Additional impacts are expected from sediment plumes produced during mining operations. Currently the greatest concern in U.S. waters appears to impacts from mining to the particularly rich deep-sea coral and sponge habitats on seamounts in the U.S. Pacific Islands (Parrish et al., this volume). Many of these occur in the Prime Crust Zone of the Central Pacific (Schlacher et al. 2014), which contains large concentrations of commercially valuable deep-sea minerals (Hein et al. 2013).

Climate Change and Ocean Acidification: There are still many unknowns concerning the potential impacts of climate change and ocean acidification on deep-sea coral ecosystems. The 2007 Report did not assign a level of threat to these ecosystems in the United States from climate change due to a lack of information (Hourigan et al. 2007). Since then, the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concluded that ocean warming has affected deep-sea ecosystems at least down to 2000 m (Hoegh-Guldberg et al. 2014). Effects of warming on deep-sea coral and sponge communities include direct impacts on survival (e.g., Brooke et al. 2013, [coral]) and growth (Stone et al. 2017, [coral]), and an array of indirect effects linked to increasing water temperature (Sweetman et al. 2017). These include decreased dissolved oxygen concentrations (Keeling et al. 2010, Levin and Le Bris 2015), altered hydrodynamics (Birchenough et al. 2015), or decreased productivity of surface waters and export of food to the deep-sea (Jones et al. 2014).

Rising atmospheric carbon dioxide (CO_2) is also directly responsible for ocean acidification with associated changes in carbonate chemistry that affect coral calcification (Guinotte et al. 2006). Ocean acidification results from net uptake by the ocean of CO_2 emissions, which decreases carbonate ion concentration in ocean waters (Feely et al. 2004). Worldwide, ocean waters from 200–3000 m are expected to face the largest reductions in pH by the year 2100 (Sweetman et al. 2017). This decrease has been forecast to hamper production of biogenic carbonates (aragonite and calcite) in the skeletons of corals, and is likely to be most problematic for reef-forming stony corals. The deep waters of the northeast Pacific have the shallowest aragonite and calcite saturation horizon, and may provide a unique opportunity to study the response of deep-sea corals to ocean acidification. Corals in this region could be surviving in potentially corrosive water conditions for some months of the year (Feely et al. 2008).

In Table 3 we have divided climate impacts into two categories – climate changes and ocean acidification. We identify the latter as a low to medium threat to deep-sea corals currently, but is likely to become a high threat in the future. Threats from ocean acidification are highest where the aragonite saturation horizon is shallowest (in the North Pacific) and where there are deep-sea scleractinian coral reefs, which are expected to be especially vulnerable to dissolution. These factors come together in the newly discovered deepwater reefs in the Northwestern Hawaiian Islands and Emperor Seamounts (Baco et al. 2017). There are likely synergies between ocean acidification and other impacts of climate change.

Compared to corals, there is little information on potential responses of sponges to climate change and ocean acidification. Kahn et al. (2012) observed changes in abyssal sponge populations correlated with climate-driven changes in particulate organic carbon. Bennett et al. (2017) presented initial experiments with shallow-water sponges that found that high temperatures may adversely affect sponge survival. In their experiments, elevated partial pressure of carbon dioxide (pCO_2) alone did not result in adverse effects, however it exacerbated temperature stress in heterotrophic sponges, but not in phototrophic species. We are not aware of similar experiments with deep-sea sponges, all of which are heterotrophic.

IV.3.iii – Vulnerability of Deep-Sea Coral and Sponge Ecosystems to Threats

Most deep-sea corals and sponges are highly vulnerable to physical impacts such as those from bottom trawling (Roberts 2009, Hogg 2010). Recovery from damage will depend on extent of the damage, and the ability of the damaged organisms to recover or for new recruits to settle and grow. This, in turn, is governed by the life-history characteristics of deep-sea corals and sponges, which tend to include slow growth, late maturity, extreme longevity, and infrequent recruitment events, all of which make these organisms particularly slow to recover from disturbances (Roberts et al. 2009, Hogg et al. 2010).

Since the 2007 Report there has been growing evidence for extreme age and slow growth of deep-sea corals (Prouty et al., this volume). Roark et al. (2009) reported that Hawaiian gold corals and one species of black coral could reach ages of 2,500 to over 4,000 years, respectively. Even relatively shallow-water holaxonian corals in Alaska may take 60 years to reach maximum size (Stone et al. 2017). There have been few studies of recruitment of deep-sea corals in U.S. waters, but most evidence points to relatively low and episodic recruitment (Cordes et al. 2016a).

Clark et al. (2016) found that corals and sponges were highly vulnerable to fishing impacts, and their life history attributes meant that, once damaged, the recovery potential of biogenic habitats was highly limited. They concluded that recovery would take decades to centuries after fishing had ceased. There have been few studies investigating recovery of damaged deep-sea coral habitats in U.S. waters, but observations to date indicate that its potential is very limited (Stone and Rooper, this volume).

Sponges are also extremely vulnerable to damage from fishing gears (Freese et al. 1999, Freese 2001, Stone 2014, Stone et al. 2014, Maldonado et al. 2016, Malecha and Heifetz 2017). Suspended sediments associated with bottom trawling may also adversely affect deep-sea sponges (Tjensvoll et al. 2013). Less is known about the life history of sponges than of deep-sea corals, however, there is growing evidence that many species are slow-growing and long-lived. The massive shallow-water demosponge, *Xestospongia muta* from the Florida Keys, is estimated to live for more than 2300 years (McMurray et al. 2008). The deep-sea glass sponge, *Monorhaphis chuni*, may hold the distinction of being the longest-lived animal on earth. Jochum et al. (2012) measured oxygen isotopic ratios and Mg/Ca ratios from a giant basal spicule of a specimen collected at 1110 m, and estimated that the sponge had been growing for 11,000 ± 3,000 years.

The glass sponge, *Aphrocallistes vastus*, is widely distributed in the northern Pacific Ocean from Panama through the Bering Sea and to Japan (Stone et al. 2011). Austin et al. (2007) concluded that juveniles of this species can reach a moderate size within 10-20 years on glass sponge reefs off British Columbia, but may require a century to reach full size. They also found that that the species was very susceptible to physical damage and that recruitment appeared to be rare at their study site. Kahn et al. (2016) observed recruitment, growth, and response to damage of glass sponge reefs over a three year period. They observed recruitment, as well as growth of sponges ranging from 0-9 cm/year, but sponges did not recover from experiments simulating larger scale damage. The authors concluded that the sponge reefs are not resilient to disturbances such as bottom trawling.

In conclusion, research over the last decade has provided increased evidence for the high vulnerability and low resilience of deep-sea coral and sponge habitats and the communities they support. This conclusion emphasizes the value of management measures to protect remaining undamaged deep-sea coral and sponge communities.

IV.3.iv – Actions to conserve U.S. deep-sea coral and sponge ecosystems

The 2007 Report summarized steps taken within U.S. waters to manage impacts to deep-sea corals and other deepwater habitats. These efforts primarily focused on NOAA's National Marine Sanctuaries and area-based fishing gear closures developed by the regional Fishery Management Councils. The latter addressed the most immediate threat to vulnerable benthic habitats: a few relatively small areas were specifically established to protect deep-sea coral habitats, e.g., the Oculina Banks Habitat Area of Particular Concern (established in 1983 and expanded in 2000), Alaska Sitka Pinnacles Marine Reserve (2000), and Aleutian Islands and Gulf of Alaska Coral Habitat Conservation Areas (2006). Additional deepwater areas in U.S. waters have been established for general habitat protection (Sutter et al. 2013).

New Areas Protected from Fishing: The 2007 Magnuson-Stevens Act reauthorization recognized the importance of deep-sea coral habitats and provided new discretionary authority to protect these habitats in their own right (MSA Sec. 303(b)(2)). Since then, Fishery Management Councils in each region have actively included deep-sea coral ecosystems in discussions of conservation measures (Hourigan 2014). Large-scale, area-based conservation measures have specifically targeted deep-sea coral ecosystems for protection. In 2010, the South Atlantic Fishery Management Council established five deepwater Coral Habitat Areas of Particular Concern that protect deepwater coral reefs in an area of 62,717 km² (Hourigan et al., this volume). The Mid-Atlantic Fishery Management Council was the first to use the new MSA discretionary authority to protect deep-sea coral habitat regardless of formal recognition as Essential Fish Habitat (Packer et al., this volume). The Council proposed the designation of the Frank R. Lautenberg Deep-Sea Coral Protection Area, encompassing more than 99,000 km² (~38,000 square miles) in 2015. NMFS approved this amendment in 2016, establishing the largest protected area in the U.S. Atlantic. This conservation approach was based on *NOAA's Strategic Plan for Deep-Sea Coral and Sponge Ecosystems*, protecting specific canyons where deep-sea corals had been found, as well as freezing the footprint of most bottom fisheries to prevent expansion into new deepwater habitats. The New England Fishery Management Council is exploring major deep-sea coral protections in 2017 using the same approach and authority.

New and Expanded National Monuments and Sanctuaries: New discoveries of rich deep-sea coral and sponge habitats have also resulted in other important advances in deep-sea conservation. In the U.S. Pacific Islands, Presidential proclamations 8335-8337 (January 2009) designated three new National Monuments: the Marianas Trench Marine National Monument, Rose Atoll Marine National Monument, and Pacific Remote Islands Marine National Monument. The Pacific Remote Islands Marine National Monument and the existing Papahānaumokuākea National Marine Monument (established in 2006) were subsequently expanded by Presidential proclamation in 2014 and 2016, respectively. These new and expanded Monuments protect important deep-sea and seamount habitats and form the largest network of marine protected areas in the U.S. (Parrish et al., this volume). In 2016, the first marine national monument in the Atlantic Ocean, the Northeast Canyons and Seamounts Marine National Monument, was established under the authority of the Antiquities Act of 1906 (Packer et al., this volume). This new monument protects several submarine canyons and the four New England seamounts in the U.S. EEZ. The Presidential Proclamation specifically referenced deep-sea corals, along with "other structure-forming fauna such as sponges and anemones," as resources that "create a foundation for vibrant deep-sea ecosystems" and are extremely sensitive to disturbance from extractive activities.

Several of NOAA's national marine sanctuaries have also undergone major expansions in the last decade. In 2008, NOAA incorporated Davidson Seamount — a volcanic seamount that is home to rich deep-sea coral and sponge habitats — into the Monterey Bay National Marine Sanctuary, providing comprehensive management in addition to the 2006 EFH bottom-gear closure. In 2012, the Fagatele Bay sanctuary expanded to protect five additional areas and became the National Marine Sanctuary of American Samoa. In 2015, NOAA expanded the boundaries of Cordell Bank and Gulf of the Farallones National Marine

Sanctuaries to an area north and west of their old boundaries, to include new deepwater areas surveyed by the Deep Sea Coral Research and Technology Program. These expansions were motivated, in part, by the discovery of important deep-sea coral habitats. Most of the existing sanctuaries have also been actively exploring the deeper extents of their protected areas (e.g., Clarke et al., this volume, and Boland et al., this volume) and incorporating results into their management plans.

Offshore Energy Management: The Bureau of Ocean Energy Management (BOEM) manages renewable energy development in federal waters. The Deepwater Horizon disaster has prompted review and strengthening of offshore oil and gas regulations (Boland et al., this volume). Mesophotic and deep-sea coral habitats will also be a priority for restoration activities in the Gulf of Mexico over the coming decade under the *Deepwater Horizon Oil Spill Final Programmatic Damage Assessment and Restoration Plan*. The last decade has also seen the first offshore leases for wind energy development off the U.S. East Coast (Packer et al., this volume). While these offshore wind farms do not extend into deep water, this development has become a major driver for regional ocean management planning efforts. A number of regions have begun to incorporate deep-sea coral observation and predicted habitat information into their broader plans to protect vulnerable ecosystems (e.g., the Mid-Atlantic Regional Council for the Ocean).

In summary, the last decade has seen deep-sea biogenic habitats, especially deep-sea coral habitats, taking an increasingly central role in ocean planning and conservation in every U.S. region. Interest in these ecosystems seems likely to continue as we learn more about their value and vulnerability.

V. Conclusions

Deep-sea coral research over the decade since the 2007 Report on the *State of Deep Coral Ecosystems of the United States* has become more targeted, systematic, and collaborative. As described in the chapters that follow, this trend has resulted in tremendous advances in our understanding of the distribution of many taxa, as well as insights into the basic biology and ecology of these organisms. In contrast, knowledge of deep-sea sponges remains rudimentary at best, despite our increasing recognition of their importance to deep-sea ecosystems. Even a basic understanding of the life history of the most important structure-forming species and their distribution in U.S. waters continues to elude researchers and managers.

The new research has led to increased awareness of the beauty, ecological importance, and fragility of deep-sea ecosystems. This awareness is manifested in new conservation measures directed toward the deep sea, especially deep-sea coral habitats. Most important among these have been the new Marine National Monuments in the U.S. Insular Pacific and Northeast U.S., and large new fishery management zones that will protect over 175,000 km^2 of deep-sea areas off the U.S. East Coast, including many important deep-sea coral habitats. Deep-sea sponge grounds have received no specific protections, though many are likely included in these recent large-scale conservation areas that address bottom-fishing.

As marine research and management move forward, conservation of these remarkable ecosystems will be enhanced by continued mapping of deep-sea biogenic habitats, and research focused on understanding their structural diversity, ecological function, and contribution to biodiversity and ecosystem productivity. Each of the following chapters contains recommendations for future research.

The next steps in conservation will use this improved understanding to apply a more targeted approach to identifying high priority areas for protection. Based on the success in "freezing the footprint" of the most damaging fishing gears, future progress will likely require management within existing fishing areas, using a collaborative approach with fishers and other resource users that promotes sustainable use while protecting the most valuable benthic communities. Future progress will also need to address increasing economic uses of deep-sea resources (e.g., deep-sea mining) and the potential impacts of a changing climate.

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