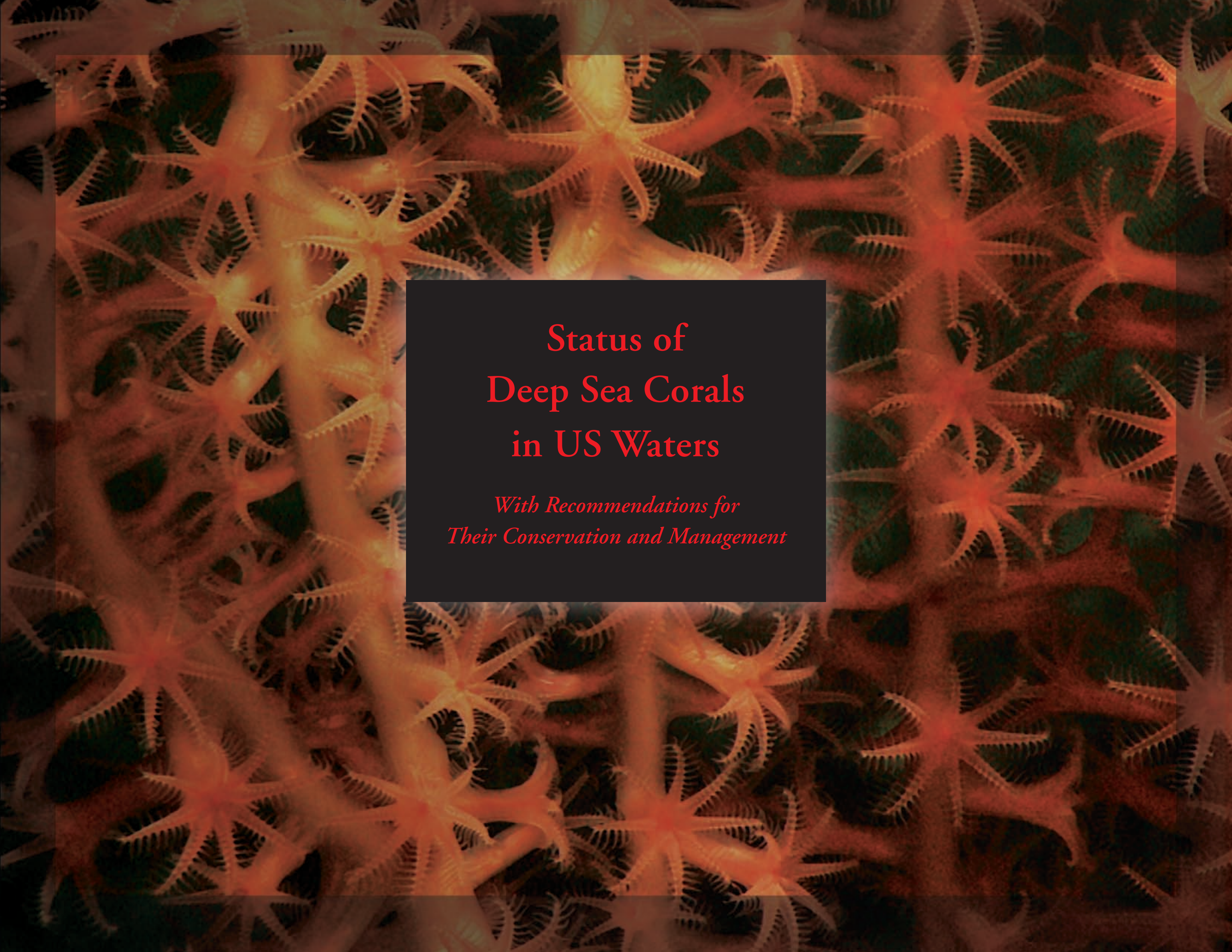
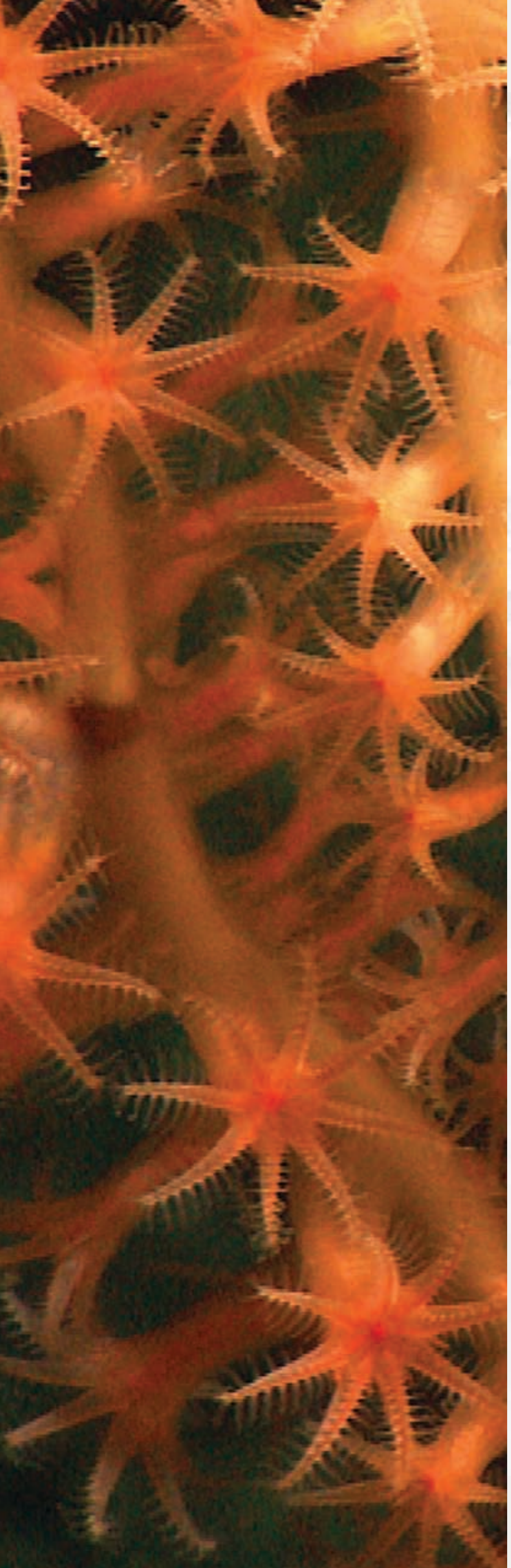


Status of Deep Sea Corals in US Waters

With Recommendations for Their Conservation and Management

"Deep sea ecosystems support bizarre and beautiful life forms, some of them hundreds or even thousands of years old. They are being clear-cut by bottom trawl fishing. Today's fisheries are squandering the riches of the deep sea and if they are not stopped we will lose them forever. No industry has the right to destroy the heritage of humanity."

Professor Callum Roberts, professor of marine conservation at the University of York in England and a Pew Fellow in Marine Conservation



Executive Summary

The ocean—especially the deep ocean—is the last frontier of exploration, exploitation and management on our planet. With demand for seafood and petroleum products exacting an ever-increasing toll on the deep sea, damage to deep sea corals is a growing worldwide conservation concern. Recent deep sea exploration has revealed spectacularly diverse seafloor communities. The deep sea corals that structure these communities provide shelter, feeding habitats, and breeding and nursery grounds to many species, including commercially important fishes. Conserving these extremely long-lived animals (some are documented to be over 1,500 years old) is also important because of their potential use in research and medicine. In this report we provide an overview of where these deep sea corals are found in US waters, what activities threaten them, and what current management actions are used to protect them. We conclude with limitations to current management and recommendations for improving deep sea coral conservation.

This report focuses on 5 taxa of deep sea corals found in US waters, stony corals, gold corals, black corals, gorgonian corals and hydrocorals. They come in various shapes and sizes, from massive reefs miles long to single bushy shaped individuals many feet tall. Our understanding of their distribution is expanding, but is currently limited and varies greatly across the different marine waters of the USA. The vast majority of the seafloor has not been surveyed for deep sea corals. What scientists do know suggests that deep sea coral concentrations are very localized, although they are widely distributed throughout the USA. They are commonly found in areas with hard seafloor substrates and appropriate currents, such as the seaward edge of the continental shelf (shelf break), around the edges of submarine canyons, and on banks and seamounts.

A number of human activities pose a threat to deep sea corals. Bottom fishing, especially bottom trawling, threatens the health and survival of deep sea corals, as well as oil and gas exploration and extraction, coral collection and a number of other human activities that contact the seafloor. Impacts from pollution, climate change and invasive species are poorly known but real threats. The effects of most of these activities are relatively unstudied and there is almost no monitoring of seafloor ecosystems anywhere in the USA. Nevertheless, bottom trawling is currently the greatest threat to deep sea corals because it is capable of significant, long-lasting damage in just one pass of the gear, and it takes place over extensive areas where there are corals.

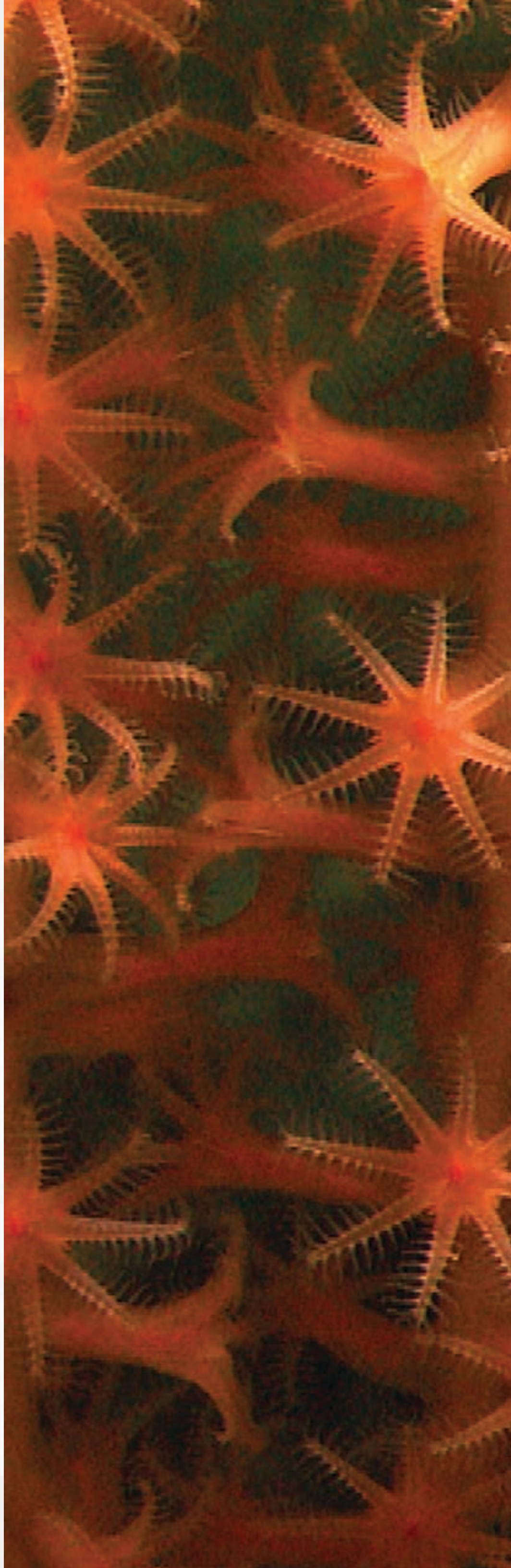
Current ocean management is insufficient to protect these vulnerable and unique deep sea habitats. Fisheries management can provide some protection under existing laws, by either closing areas to fishing or through the designation of essential fish habitat (EFH) for commercially managed species. Several of the fishery management councils have recently designated deep sea corals as EFH and restricted bottom fishing and/or bottom trawling in some cases.

Where areas have been designated, enforcement and monitoring are critically needed. *Oculina* Bank, designated as a Habitat Area of Particular Concern in 1984, in an action years ahead of its time, is now over 90% destroyed because no attention to enforcement followed the designation.

Our National Marine Sanctuary Program, the main federal program charged with protecting ocean ecosystems, does not manage fish and therefore does not regulate the impacts of fishing on deep sea corals or seafloors within its boundaries. The Minerals Management Service, which oversees energy production, can mitigate impacts to deep sea corals by establishing buffer zones around deep sea coral communities, but has yet to do so.

The findings of this report, the first to address the status of deep sea corals in US waters, echo and reinforce recent conclusions by the National Research Council in 2002, the Pew Oceans Commission in 2003, and the US Commission on Ocean Policy in 2004—which find bottom fishing, especially bottom trawling, is a major threat to seafloor communities and deep sea corals. These studies recommend stricter protection of vulnerable deep sea coral habitats. Similarly, the President's 2004 Ocean Action Plan emphasized deep sea coral conservation and called for further identification and protection of deep sea coral areas. Despite these encouraging signs, progress towards increased deep sea coral protection has been slow to occur. Recent actions by fishery management councils to designate essential fish habitat and to freeze the current footprint of bottom trawling are progress for deep sea coral conservation. But those areas that have been comprehensively protected are small in relation to the need.

The recommendations of this report are first, that fishery management councils and national marine sanctuaries must use existing tools to protect deep sea corals, and curtail any further expansion of bottom trawling unless it can be shown that trawling will not damage seafloor habitats. Second, a national mandate to protect deep sea corals is necessary through either amendment to the Magnuson-Stevens Act or new legislation. Third, government should devote substantial resources to achieving a better scientific understanding of where deep sea coral communities are found, their ecological roles and threats to them, especially bottom-contact fishing gears. Last, managers must develop a comprehensive framework to manage all human activities based on their compatibility with different ocean habitats (i.e., ecosystem-based management and ocean zoning). Until we make protecting ecosystems, rather than exploiting resources, the overarching goal of management, we will continue to fall short of protecting deep sea corals, sustaining healthy fisheries, and maintaining the oceans' productivity and biological diversity.



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Front cover photo: A close-up of bamboo coral polyps on a seamount off New England
Photo credit: Deep Atlantic Stepping Stones Science Party, IFE, URI-IAO, and NOAA

Inside front cover photo: An assemblage of sponges and corals in the Aleutian Islands, Alaska
Photo credit: A. Lindner, NMFS

This page: A close-up of a gorgonian coral (Iridogorgia *sp.) on a seamount off New England. The feeding polyps are all lined up on one side of the branches.*
Photo credit: the Deep Atlantic Stepping Stones Science Party, IFE, URI-IAO, and NOAA

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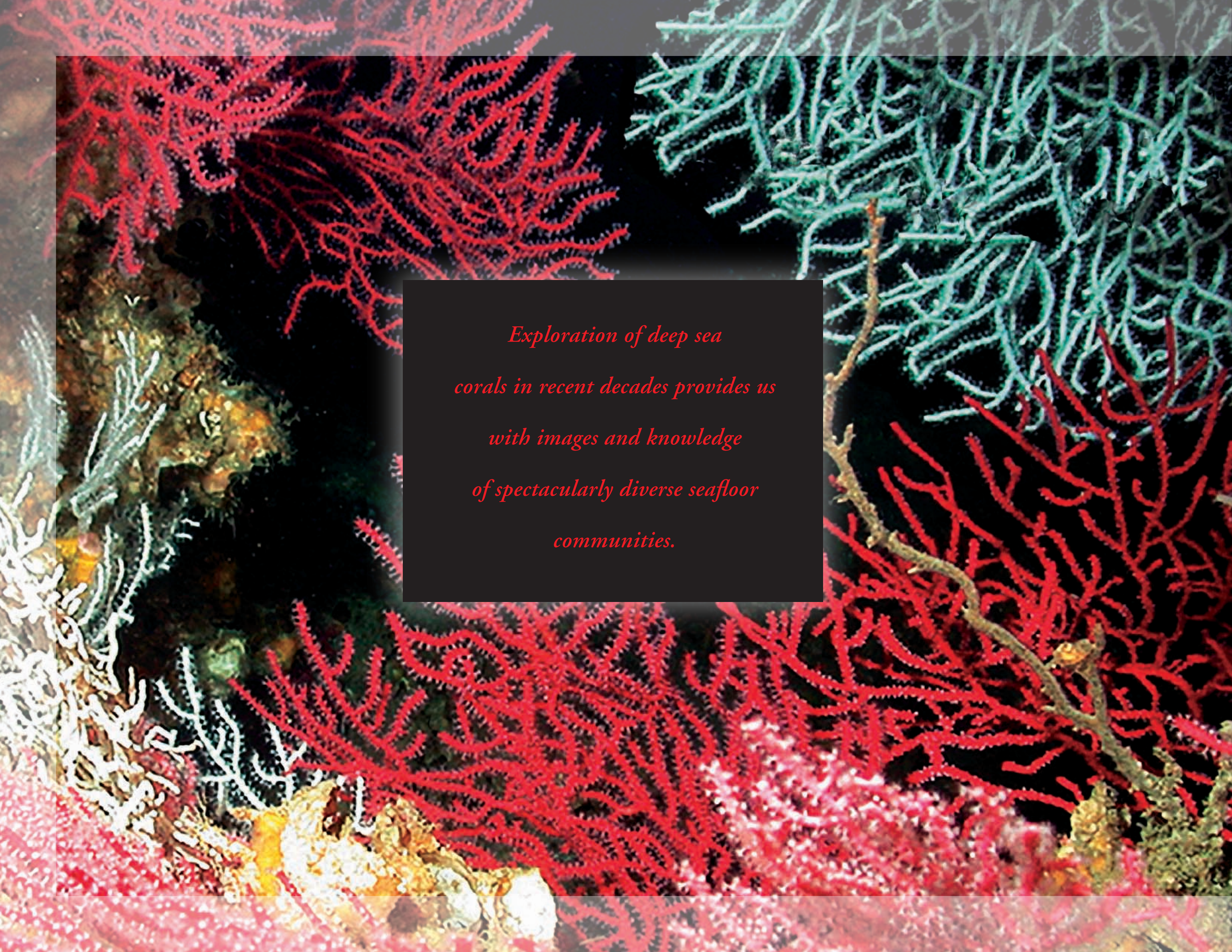


Exploration of deep sea corals in recent decades provides us with images and knowledge of spectacularly diverse seafloor communities.

Voyage to the Bottom of the Sea

The ocean—especially the deep ocean—is the last frontier we are exploring and exploiting on our planet. As recently as the late 1800s, scientists debated whether or not life existed below the depths to which light penetrates (roughly 660 ft). Today we know that life extends to the deepest ocean depths—below 35,000 ft to the bottom of the Marianas Trench. We are still discovering new deep sea species at a rapid rate. Photographs from research cruises show astoundingly beautiful corals—many new to science—and spectacular, lush coral forests sheltering diverse communities of sea life. Along with these discoveries comes increasing knowledge of the fragility and vulnerability of many species—especially deep sea corals. Recent exploration of the marine realm, aided by remotely operated vehicles (ROVs) and manned submersibles, has provided compelling evidence that our stewardship of the deep sea is insufficient. Images brought back by researchers document deep sea corals damaged or crushed by fishing gears. We are destroying a treasure that we have yet to fully understand. Until we comprehend the complexity and interconnectivity of marine biodiversity, we cannot begin to fathom the impact that the destruction of this diversity will have on our ocean and on us. In the face of our ignorance and the growing threat to deep sea coral habitats, more than 1,400 marine and conservation scientists worldwide have called upon the United Nations and national governments to protect deep sea corals.[1] This report provides a comprehensive overview of the status of and threats to deep sea corals in US waters in the hope that understanding current knowledge of these animals will help us all make the decisions necessary to protect them.

As coastal fish populations decline from overfishing and habitat degradation, commercial fishing fleets are moving further out into deeper waters (Christensen et al. 2003, Roberts 2002). Industrialized fleets are now using advanced technologies (e.g., synthetic fishing gears, larger and more capable ships, satellite navigation systems, computers and electronics) to find and catch fish at ever greater depths. With demand for seafood and petroleum products exacting an ever-increasing toll on the deep sea (Glover and Smith 2003), damage to deep sea corals is a growing worldwide conservation concern (Hain et al. 2004). The significance of this damage is further amplified because deep sea corals are among the longest-lived animals on Earth—hundreds to thousands of years old—and are exceptionally fragile.

[1] Scientists' Statement on Protecting the World's Deep-sea Coral and Sponge Ecosystems (http://www.mcbi.org/DSC_statement/sign.htm)

What are Deep Sea Corals?

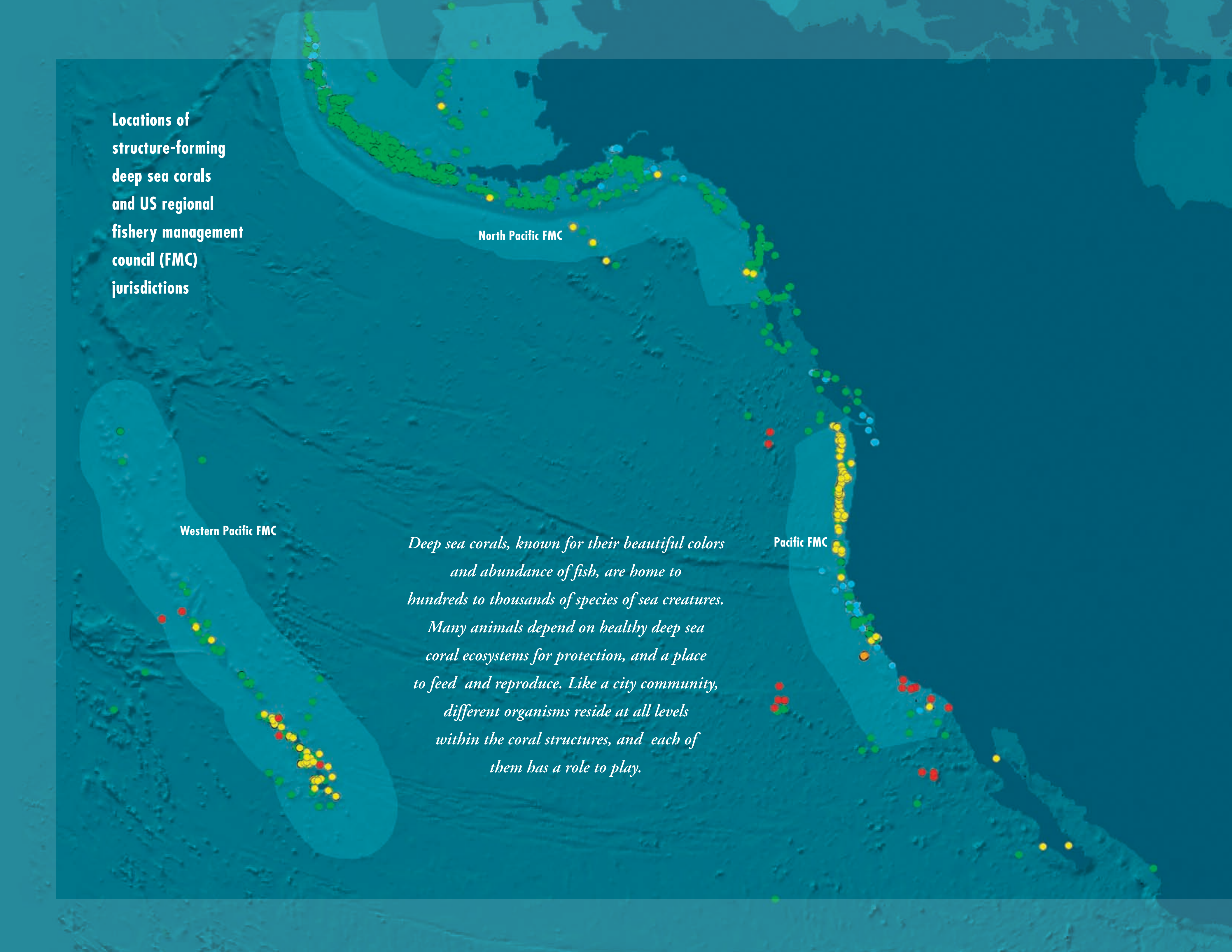
Deep sea corals are not a single taxonomic group of animals; they are a functional group—analogous to the diverse plants included under the descriptors "bushes" or "trees."

Gorgonians in the Gulf of Mexico
Photo credit: L. Horn, NURC/UNCW

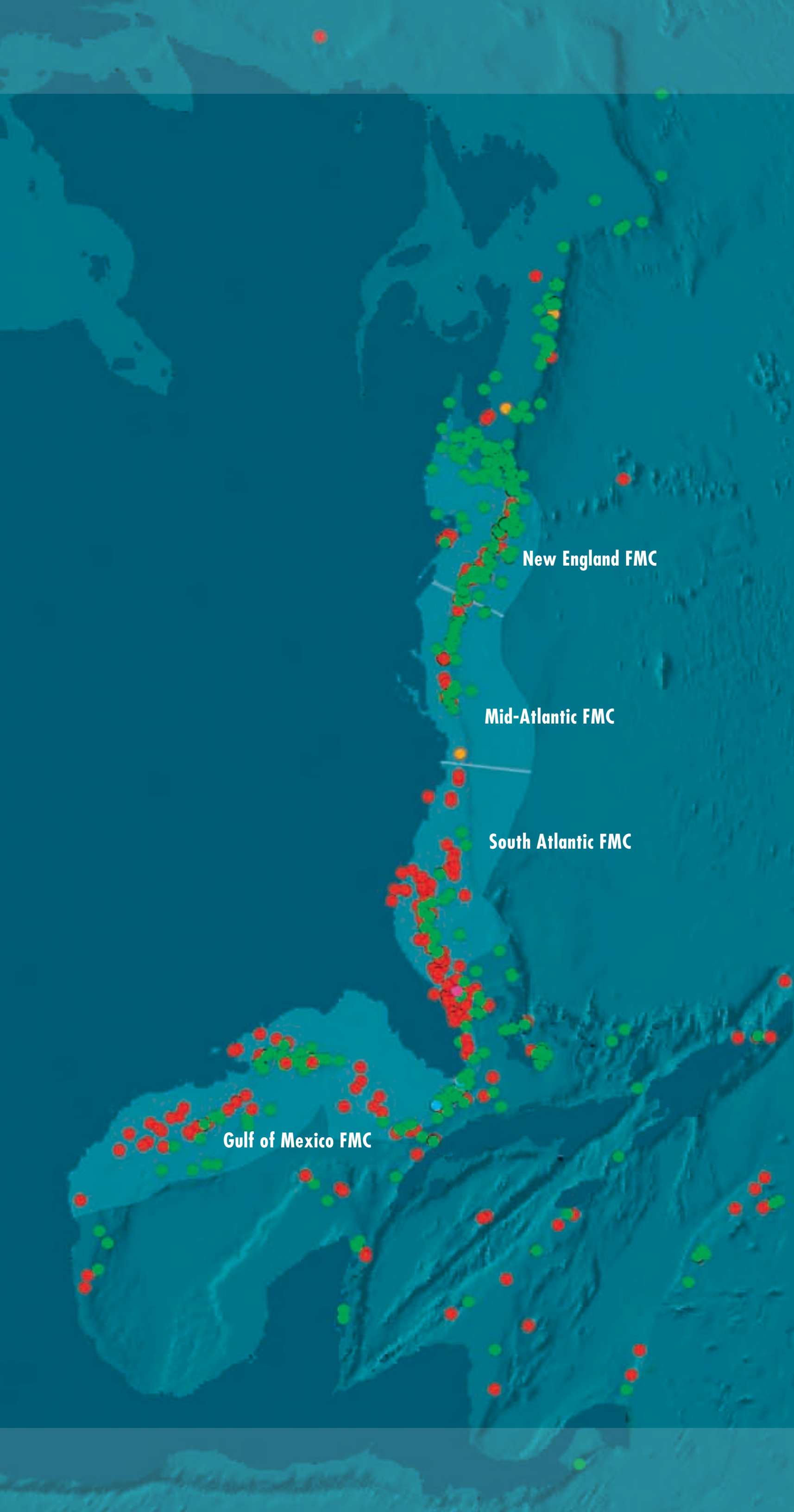
Stony corals off North Carolina
Photo credit: S.W. Ross et al., UNCW

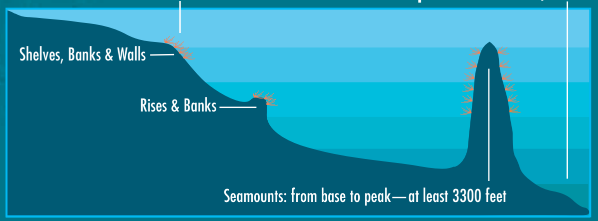
Opposite page: Deep sea corals at Madison-Swanson protected area in the Gulf of Mexico.
Photo credit: L. Horn, NURP/UNCW

Locations of structure-forming deep sea corals and US regional fishery management council (FMC) jurisdictions



Deep sea corals, known for their beautiful colors and abundance of fish, are home to hundreds to thousands of species of sea creatures. Many animals depend on healthy deep sea coral ecosystems for protection, and a place to feed and reproduce. Like a city community, different organisms reside at all levels within the coral structures, and each of them has a role to play.





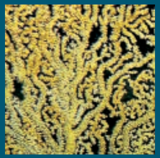
The type of corals that most people are familiar with, such as the stony corals that form the Great Barrier Reef in Australia, are different from corals found in deeper waters in one significant way: shallow-water, reef-building corals contain symbiotic algae which provide the corals with nutrients. Like most plants, algae are able to convert the sun's energy into food through a process called photosynthesis. Corals with symbiotic algae are only found in the upper layers of the sea where sunlight can penetrate (the photic zone), and are usually found near shore in shallow waters adjacent to islands.

By contrast, deep sea corals do not contain symbiotic algae and can thrive at depths below the sun's reach. The deepest known coral came from a depth nearly four miles below the oceans surface! Deep sea corals tend to occur on "hilly" surfaces or where the slope changes abruptly; areas such as the shelf break (the seaward edge of the continental shelf), the continental slope (a much steeper part of the seafloor, seaward of the shelf), and on ridges and seamounts (mountains hundreds or even thousands of feet tall that rise from the seafloor). For example, deep sea stony corals form banks on the continental slope off the southeastern USA, and deep sea gorgonian corals grow on the steep slopes off the Aleutian islands and atop seamounts in waters offshore of California, Hawaii, in the Gulf of Alaska, and throughout the New England Seamount chain.

Not illustrated is the Caribbean FMC including waters surrounding Puerto Rico and the US Virgin Islands. Lightly shaded region denotes US exclusive economic zone. Orange dots represent unknown coral records.

• STONY CORALS

Colonies of stony corals grow together to form large mounds or reefs. They have numerous short, white branches.



• GOLD CORALS

Gold corals are colonies of individuals that grow into branching bush like structures. Growing slowly, some of these corals are estimated at 1,800 years old.

• BLACK CORALS

Black coral colonies have extensive branching patterns which often resemble trees. Though not black while living, the underlying skeleton is black or dark brown.

• GORGONIAN CORALS

Gorgonian corals have a flexible internal skeleton that allows them to bend and sway in the currents. They are found on continental shelf breaks, submarine canyons and isolated seamounts.

• HYDROCORALS

Hydrocorals form a rigid but relatively brittle calcium carbonate skeleton with numerous pinpoint-sized pores and can be a variety of colors.

An *Iridogorgia* sp. coral growing on a New England seamount
Photo credit: the Deep Atlantic Stepping Stones Science Party, IFE, URI-IAO, and NOAA

"A vast expanse of the planet's unexplored, and potentially most promising, ocean beyond the legal boundaries of nations is being exposed to the reckless plunder of marauding deep sea fishing trawlers."

Jean-Michel Cousteau, Founder and President, Ocean Futures Society

Just as trees include ferns, several families of conifers, and several major groups of flowering plants, deep sea corals include members of a number of different taxonomic groups, including stony corals, gold corals, black corals, gorgonian corals, and hydrocorals. Several things unite the deep sea corals we discuss in this report. They are all members of the phylum Cnidaria, from the Greek word "cnidos" meaning stinging nettle. All cnidarians use modified stinging cells to protect themselves and capture prey. While most tropical coral reefs rely primarily on photosynthesis by symbiotic algae for nourishment, deep sea corals lack symbiotic algae and capture all of their food using stinging cells. Some scientists are investigating whether microbial communities inhabiting deep sea corals may serve functions similar to symbiotic, photosynthetic algae in shallow corals. Where planktonic food particles are available in the deep sea, corals can thrive well beyond the depths to which light penetrates. These corals are variously referred to as deep sea corals, cold water corals, and deep water corals. We use the term "deep sea corals" in this report.

Deep sea corals can grow alone or in colonies, and they come in various colors, shapes, and sizes. Although corals are animals, they are often compared to plants because some (for example black corals, gorgonian corals, and hydrocorals) branch out in bushy or tree-like shapes, resembling forests, groves, and thickets. Additionally, some species of stony corals, including the relatively well-studied species *Lophelia pertusa* and *Oculina varicosa*, develop large reefs. As colonies of these corals increase in size, their complex structure traps sediments at the base. Over time, the dead coral and sediment accumulate, forming a characteristic deep sea coral reef, or "bioherm," with a cap of live coral. Many other types of deep sea coral are relatively small or occur alone. Our focus in this report is on those deep sea corals that grow into "bushes" and "trees," or form reefs.

Why Should We Be Concerned about Deep Sea Corals?

Deep sea corals are long-lived animals that often provide habitat for a diverse array of marine life, including commercially valuable fishery species. They also have untapped potential to produce novel medical compounds and have been valued as jewelry for millennia.

Longevity and Vulnerability

Living in cold water, often at great depths, deep sea corals grow very slowly and have extraordinarily long life spans—up to hundreds or even thousands of years (Figure 1.1). Red-tree corals (*Primnoa resedaeformis*) from southeast Alaska are 100 to 200 years old by the time they reach 6 to 10 ft in height (Andrews et al. 2002).

The same species in Atlantic Canada lives more than 300 years (Risk et al. 2002). A colony of gold coral (*Gerardia* sp.) living in water depths of 1,900 feet off Little Bahama Bank, was determined to be about 1,800 years old, making it one of the longest lived organisms on Earth; researchers likened it to the bristlecone pine because of this tremendous longevity (Druffel et al. 1995).

The ivory-tree coral *Oculina varicosa*, found in the southeast USA, grows about 0.6 inches a year, yet has formed 80 ft high reefs off Florida that are estimated to be 1,500 years old (Reed 2002a). On a stony coral *Lophelia* reef off Florida, live corals may be as old as 700 years, and rubble from dead coral is over 20,000 years old (Reed 2002a). Existing *Lophelia* reefs in the Gulf of Mexico may be 40,000 years old (Reed 2002a)!

Medical and Scientific Value

Because deep sea corals are stationary animals that cannot evade predators by moving away, some species rely on chemical defense mechanisms to protect themselves (Faulkner 2002). These mechanisms generate compounds that exhibit significant bioactivity (effects on living cells or organisms). Some of these compounds show promise as treatments for human ailments. Scientists are studying extracts of deep sea corals, sponges, and other organisms to develop new pharmaceutical products to fight cancer, Alzheimer's disease, asthma, pain, and viral infections (Box 1.1). Some of these compounds are also used in paints and other materials to prevent algae and invertebrates from growing on boat hulls, piers, and bridges.

In addition to their potential value as medical therapies, deep sea corals are also archives of the ocean's history (Box 1.2). Changes in ocean conditions are naturally recorded in the skeletons of corals, and because deep sea corals live a very long time and are distributed across a wide range of depths and latitudes, they provide an excellent window into the ocean's history (Risk et al. 2005, S.W. Ross et al., unpublished data, UNC-Wilmington). As scientists continue to develop techniques to measure the age and growth of deep sea corals and to interpret the changes in these measurements, corals will help reconstruct the history of changes in growth, temperature, and ocean chemistry at great depths beneath the sea.

The tremendous longevity of deep sea corals makes them valuable archives of past conditions on Earth. Furthermore, the erect, branching skeletons of deep sea corals are fragile and easily damaged by disturbances such as mobile bottom fishing gears. Once damaged, these invaluable archives are lost to science, and these seafloor communities may need decades to millennia to recover, if they are able to recover at all.

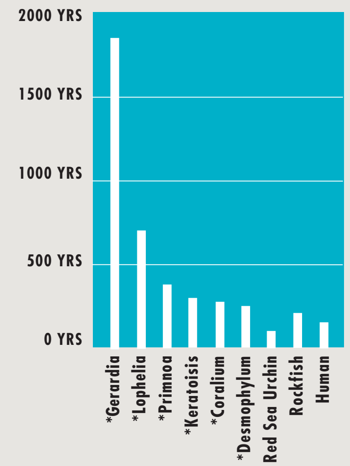
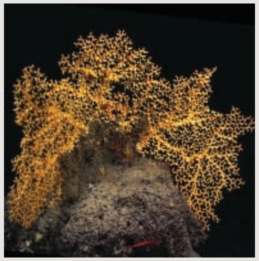


Fig. 1.1: Ages of deep sea corals (*) and other animals from selected studies

Andrews et al. 2002, Andrews et al. 2005, Caillet et al. 2001, Druffel et al. 1995, Ebert and Southon 2003, Paull et al. 2000, Risk et al. 2002

"The disaster of bottom trawling on the high seas threatens thousands of species and can mean a reversal in evolution of tens of thousands of years."

Mikhail Gorbachev, Chairman of the Board, Green Cross International



A stony coral colony (*Enallopsammia* sp.) growing on top of a rock.
Photo credit: the Deep Atlantic Stepping Stones Science Party, IFE, URI-IAO, and NOAA

"About 98 percent of the oceans' species live in, on or just above the seafloor. Many of them including ancient deep-sea corals and sponges haven't even been discovered yet."

Dr. Elliott A. Norse, President of Marine Conservation Biology Institute in Bellevue, WA

Deep Sea Corals as Habitat

As anyone who fishes, snorkels, or dives knows, fish are often encountered in or near places with complex, three-dimensional habitat—for example, kelp forests, coral reefs, and seagrass beds. The amount of three-dimensional habitat on the seafloor generally correlates with the level of biodiversity (Krieger 1993, Love et al. 1991, Risk 1972, Yoklavich et al. 2000). Many deep sea corals form complex, three-dimensional habitats. The spaces and gaps between coral branches serve as shelter and refuge for the eggs, larvae, and juveniles of shrimps, crabs, and fishes, and for many of the adults as well (e.g., Krieger and Wing 2002, Reed 2002b, Reed et al. 2006). A variety of animals forage within deep sea coral areas (Box 1.3), and filter-feeding animals use deep sea corals as a feeding platform that is raised into the higher-current zone above the sea-floor, where more food is available (e.g., Buhl-Mortensen and Mortensen 2005, Krieger and Wing 2002).

Coral ecosystems not only increase local microhabitat, but may also cover vast areas, thus providing resources to uncountable numbers and types of creatures. For example, the Røst Reef located in northern Norway, the largest known deep sea coral reef, is approximately 25 miles long and 1.5 miles wide, covering an area of about 40 mi^2 (Fosså et al. 2005). Those corals that do not create reefs but grow as individual colonies (gold corals, black corals, gorgonian corals, and hydrocorals), also increase structural complexity, particularly if they occur at high densities or are extremely large. Other invertebrates (especially sponges) that co-occur with these corals also contribute to habitat structure (Freese 2001). Studies in the Aleutian Islands suggest that corals and sponges may serve as "keystone structures" that provide

Box 1.1: Drugs from the Deep Sea

There are currently several drugs in development that are derived from compounds found in deep sea organisms (Maxwell et al. 2005).

Discodermolide. This promising drug recently completed the early stages of clinical trials and is one of the most exciting anticancer compounds to date, because it may treat cancers that are resistant to other drugs. It is isolated from the sponge *Discodermia dissoluta*, found off the coast of the Bahamas in water over 460 ft deep.

E7389. This compound comes from the sponge *Lissodendoryx* sp., which lives in New Zealand waters at depths of 3,330 ft. E7389 is being tested for the treatment of lung and other cancers and is currently undergoing the early stages of clinical trials.

Dictyostatin-1. A sponge from the order Lithistida (family Corallistadae), found at 1,450 ft off the northern coast of Jamaica, yielded Dictyostatin-1, which may be more effective than the very successful anti-cancer drug Taxol®.

Topsentin. Isolated from the sponge *Spongosporites ruetzerli*, which lives at depths of 990 to 1,980 ft, Topsentin shows promise as an anti-inflammatory agent to treat arthritis and skin irritations, as well as for the treatment of Alzheimer's disease and to prevent colon cancer.

Bone Grafts. Scientists are now able to synthesize bone analogs from bamboo corals. Found at depths that can exceed 3,280 ft, these corals have a skeletal structure and dimensions that are almost identical to bone.

Collagen. Bamboo corals also contain gorgonin, which closely resembles collagen, an important component of bone. Collagen can be used for controlled release of medicines, as scaffolding for tissue rebuilding, and for a variety of other applications. Scientists hope that by understanding how corals form gorgonin, they can create a synthetic collagen-like material under the low temperature and high pressure environments that bamboo corals naturally inhabit.

"goods and services" (food resources and shelter) crucial to the survival of associated animals (Heifetz et al. 2005, Tews et al. 2004).

Habitat for Invertebrates

Many studies have found high species diversity where deep sea corals are densely distributed (Roberts et al. 2006). One deep sea coral reef was home to 3 times as many species as the surrounding sandy seafloor (Mortensen et al. 1995). In Atlantic Canada, deep sea gorgonian corals host 114 species—more than some tropical gorgonian coral communities—and support a variety of invertebrates, including crabs, shrimps, clams, snails, and worms (Buhl-Mortensen and Mortensen 2005). In waters off the southeastern USA, a study of *Oculina* colonies found more than 300 species of invertebrates and over 70 species of fish associated with this coral (Reed et al. 1982, Reed 2002b). *Lophelia* reefs in the northeast Atlantic host more than 1,300 species (Roberts et al. 2006) and are home to more animals of more different species than surrounding habitats (Costello et al. 2005).

The standing dead portions of large coral colonies are as valuable as, if not more so, than the living portions. A wide range of encrusting and boring organisms use the dead coral skeleton for habitat. For example, dead *Lophelia* colonies in the Florida Straits support sessile organisms such as feather stars and sea anemones that need hard substrate for attachment and are not otherwise found on the surrounding seafloor (Messing et al. 1990). Structure-forming corals are biodiversity hotspots in the deep sea (Jensen and Fredericksen 1992, Raes and Vanreusel 2005).

Habitat for Fishes

Fish species diversity is directly correlated with three-dimensional habitat on tropical coral reefs (Connell and Jones 1991, Friedlander and Parrish 1998), because complex habitats provide more refuges

Mystery mollusk (Order Nudibranchia) above the Davidson Seamount at 4,943 ft depth. Exploration of the deep sea is discovering many species new to science.
Photo credit: B. Walden, NOAA/MBARI

Yellow sponges surrounding a glass sponge on a seamount off New England.
Photo credit: the Deep Atlantic Stepping Stones Science Party, IFE, URI-IAO, and NOAA

Growth Rings of a Bamboo Coral Skeleton
The width of the cross section is approximately 0.4 in. Formation of these rings is affected by the condition of the seawater around the coral colony.
Photo credit: Courtesy of NIWA and Sanchez et al. 2004

Box 1.2: Climate Information Archived in Deep Sea Corals

Over the long life of a coral, its growth pattern records information on how ocean chemistry and even global climate have changed. Methods to read these archives are still being perfected, but exciting progress has been reported in recent years. Researchers analyzed fossils of the stony coral *Desmophyllum cristagalli* collected off Newfoundland and found a sudden change in one specimen's isotopic composition during its lifetime as well as a major difference between this specimen and other specimens that lived at different times but in the same region. This pattern is a signal of rapid climate change—the Younger Dryas cooling event, a mini ice-age that took place 13,000 years ago (Smith et al. 1997).

from predators than less rugged habitats (Risk 1972). The mortality rates of juvenile fish are greatly reduced when there is abundant refuge from prey (Hixon and Jones 2005, Lindholm et al. 2001), and this may have important population-level effects (Lindholm et al. 1999). The diversity, quality, and extent of seafloor habitats are vital determinants of the diversity, distribution, and abundance of valuable commercial species such as rockfishes (Carr 1991, Nasby-Lucas et al. 2002, O'Connell and Carlisle 1993, Pearcy et al. 1989). The degree to which structure-forming deep sea corals and sponges provide habitat for fish species depends on their size, density, growth form, and the interaction of the fish with the coral structure (Mortensen and Buhl-Mortensen 2006, Pirtle 2005, Tissot et al. 2006).

Surveys of European waters have discovered many different species of fish in *Lophelia* reefs, including cod, saithe, ling, tusk, rabbitfish, redfishes, and others (Costello et al. 2005, Fosså et al. 2002, Husebø et al. 2002). Trawl nets containing large amounts of *Lophelia pertusa* coral material also caught at least 13 species of fish, such as grenadiers, orange roughy, and various sharks (Hall-Spencer et al. 2002). Coral habitats may also be more productive than surrounding areas: fishes found associated with *Lophelia* reefs in Norway were larger than those in non-coral habitats (Husebø et al. 2002). Thus, *Lophelia* reef habitats may be functionally important to deep sea fish species (Costello et al. 2005).

In Alaska, Heifetz (2002) found Atka mackerel and rockfish commonly associated with corals. In a study in southeast Alaska, 85% of the observed large rockfishes were in and around red-tree coral colonies (Krieger and Wing 2002). In the Aleutian Islands, 85% of economically important fishes and crabs and 97% of juvenile rockfishes were observed associated with corals and other structure-forming invertebrates (Stone 2006).

Deep sea coral beds are foraging grounds for a number of species including Hawaiian monk seals.

Box 1.3: Deep Sea Corals as Foraging Grounds

In 2003 researches were fortunate enough to film an endangered Hawaiian monk seal swimming among gold coral colonies at 1,740 ft depth, in the Northwestern Hawaiian Islands. Other research has shown that monk seals also forage

Hawaiian monk seal
Photo credit: J. Palmer, NMFS

in gold, pink and black coral beds feeding on eels and bottomfishes (Parrish et al. 2002).

NOAA Ocean Explorer Northwestern Hawaiian Islands 2003 Expedition: http://oceanexplorer.noaa.gov/explorations/03nwhi/media/monkseal-video.html

In the southeastern USA, scientists have suggested a strong association between deep sea coral (and other rugged habitats) and certain fish species (Ross and Nizinski in prep.). The *Oculina* reefs off Florida were identified as spawning habitat for various species of grouper, although gag and scamp groupers have undergone severe declines in the last decade (Reed et al. 2005a). Juvenile speckled hind (also a grouper) have been observed in *Oculina* reefs, which suggests that the reefs may be an important nursery habitat for fish (Gilmore and Jones 1992, Koenig et al. 2005). Fish populations from the deep sea coral habitats of the Pourtales Terrace (south Florida Straits) include several important commercial fishes, including snappers, groupers and sharks (Reed et al. 2005b).

In addition to serving as structurally complex habitats for various species of invertebrates, fishes, and mammals, deep sea corals may also be prey for other seafloor animals (Box 1.4). Despite recent progress in deep sea coral research, scientists are still at a very early stage in understanding deep sea coral communities and dynamics, and much has yet to be discovered.

Summary

Deep sea exploration is revealing spectacularly diverse seafloor communities. The deep sea corals that structure these communities provide shelter, feeding habitats, and breeding and nursery grounds to many species, including commercially important fishes. Conserving these long-lived animals is also important because of their potential use in climate research and medicine. In this report we provide an overview of where these deep sea corals are found in US waters (Chapter 2), what activities threaten them (Chapter 3), and what current management actions are used to protect them (Chapter 4). We conclude with limitations to current management and recommendations for improving deep sea coral conservation (Chapter 5).

Sea star preying on the live polyps of a bamboo coral colony.
Photo credit: Mountains in the Sea, NOAA

BOX 1.4: Deep Sea Corals as Prey

Deep sea corals are not only shelters and feeding platforms but also prey. A number of species feed on deep sea coral polyps directly. For example, parasitic copepods, worms, anemones, sea stars, sea slugs, and snails prey on gorgonian corals, such as bamboo corals (e.g., Buhl-Mortensen and Mortensen 2005, Krieger and Wing 2002).

Deep sea corals come in various shapes and sizes, from massive reefs miles long to single polyps the size of one's finger tip.

Deep Sea Corals in US Waters

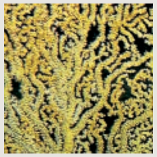
Deep sea corals fall within the phylum Cnidaria. Their characteristic trait is the presence of stinging cells, which provide defense against predation and a means of obtaining food. Shallow water corals retain symbiotic algae that use sunlight to produce energy for themselves and their coral hosts. Deep sea corals live beyond the depths at which algae can photosynthesize; therefore, they rely entirely on catching food particles from the water column. Despite these common traits and their sedentary existence, deep sea corals vary widely in morphology, color, size, habitat, life history, and depth range. Some have a cosmopolitan distribution, while others are endemic to a limited area. For the purposes of this review, we examine the distribution of 5 broad taxa of deep sea corals (Figure 2.1) that typically inhabit rocky, hard-bottom areas and provide shelter to other forms of seafloor life:

- Stony corals (Scleractinia)
- Gold corals (Zoanthidea)
- Black corals (Antipatharia)
- Gorgonian corals (Alcyonacea)
- Hydrocorals (Stylasterina)

Distribution of Deep Sea Corals

Deep sea corals are widely distributed throughout US waters (Map 1), but several factors limit where they will thrive: substrate type, current speed, seafloor relief (ruggedness of the seafloor), nutrient availability, and temperature (Freiwald et al. 2004). The deep sea coral species discussed in this report need a hard, rocky substrate on which to attach as larvae. Currents are also important and serve to supply food particles and to prevent sedimentation (deVogeleare et al. 2005, Duineveld et al. 2004, Freiwald 2003, Genin et al. 1986, Roberts et al. 2003). Fan-shaped corals and sponges often orient their broadest profile across the current to maximize their access to food carried in the prevailing current flow. However, currents may also be detrimental to corals, such as during benthic storms when turbulence can resuspend sediments that may bury corals.

Seafloor relief, or topography, influences currents and therefore plays a key role in coral distribution. Both at small and large scales, features that increase vertical relief, and therefore current speeds—such as the shelf breaks, offshore banks, and the slopes and ridges of canyons and seamounts—also increase the suitability of the area for deep sea corals. Map 2 (*next page*) shows a slope gradient analysis which suggests that deep sea corals in the Mid-Atlantic and New England regions are found in greater abundance in areas with the steepest slopes (see Appendix for coral record data sources). Off the southeastern USA, the interaction of the Florida Current and the Gulf Stream with the topography of the seafloor is thought to be an important factor influencing the abundance of corals (Popenoe and Manheim 2001, Reed et al. 2006). Similarly, observations from



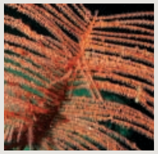
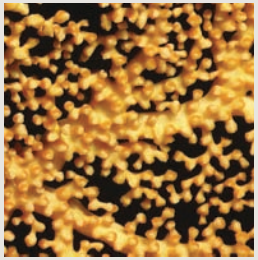
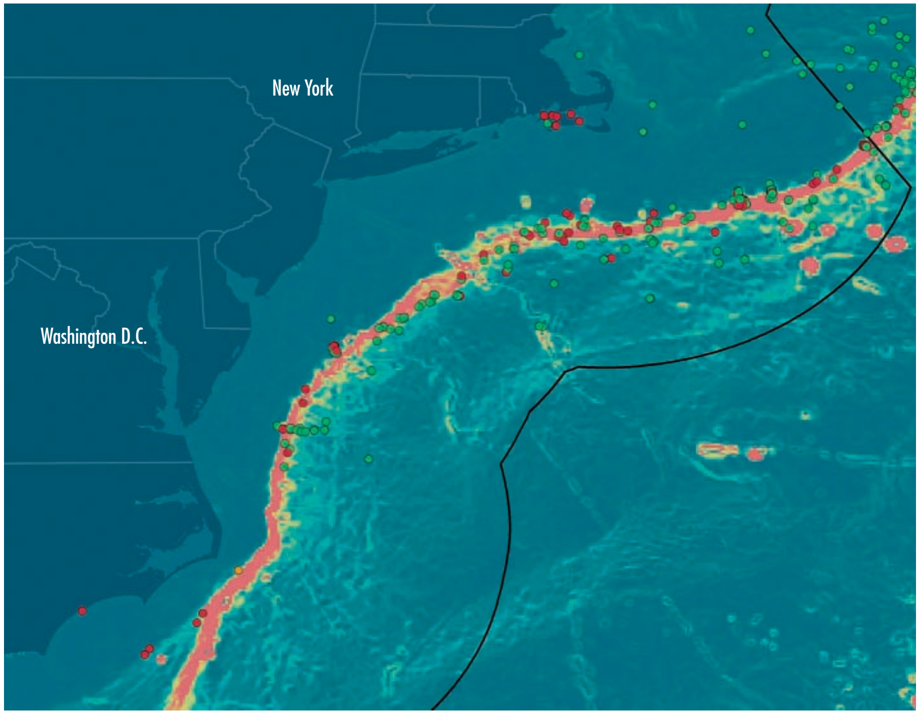


Fig.2.1, From Top: Stony coral Gold coral,Black coral, Gorgonian coral, and Hydrocoral

Opposite page: Coral polyps on Molasses Reef, Florida Keys National Marine Sanctuary Photo credit: Brent Deuel



Stony coral (*Enallopsammia* sp.)
Image courtesy of the Deep Atlantic Stepping Stones Science Party, IFE, URI-IAO, and NOAA

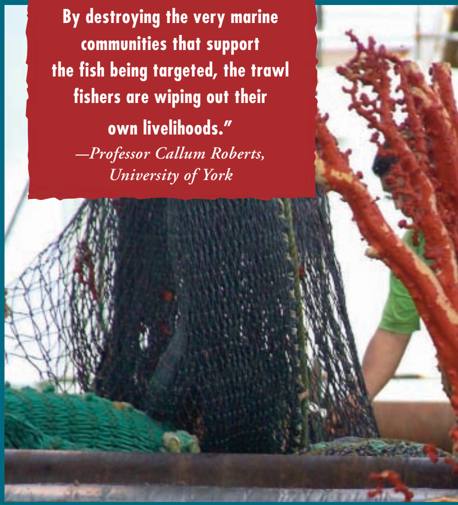


Map 2: Deep sea corals tend to occur in high-relief areas. This map represents an analysis of steepness (slope) for the Mid-Atlantic and New England regions, overlaid with deep sea coral records. Deep sea corals are abundant in areas with steeper slopes (red color), gentle slopes (blue color). Corals: ● stony corals, ● gorgonian corals. Black line is US EEZ.

Davidson Seamount off California, suggest that gorgonian and black corals concentrate on ridges where currents are accelerated (Andrews et al. 2005, deVogeleare et al. 2005).

Many corals are observed on rugged surfaces such as ridges and peaks or on boulders, ledges, and rocky outcrops. For example, the walls of sinkholes off southern Florida have high densities of gorgonian corals and hydrocorals (Reed et al. 2005b). On bioherms in the northeastern Straits of Florida, corals are segregated by zone; gold corals on the up-current crest, *Lophelia pertusa* on the up-current slope, and gorgonian corals on the flanks and the downstream crest (Messing et al. 1990). This suggests

"Bottom trawling is environmental vandalism, but also economic madness. By destroying the very marine communities that support the fish being targeted, the trawl fishers are wiping out their own livelihoods."
—Professor Callum Roberts, University of York



Box 2.1: Deep Sea Coral Distributions and Shifting Baselines

Historically, deep sea corals were likely present in many areas along the US continental shelf. Since no baseline studies on the distribution of deep sea corals were conducted, it is impossible to determine their former abundance, but reports and anecdotes from fishermen serve as evidence that the seafloor, at least in some areas, has been greatly altered by fishing. One of the first reports of deep sea corals on the West Coast is of a hydrocoral that was hauled up in fishing gear near San Francisco in the late 19th century (Dall 1884). Similar records exist from Georges Bank in New England (Verrill 1878). Canadian fishermen from Nova Scotia were quoted in a 1997 report, "35, 40 years ago, the Stone Fence was full of trees. You couldn't set halibut gear there. They'd haul up

Damage by bottom trawl fisheries is a threat to survival of deep sea corals. The Royal Society of New Zealand's Committee on Biodiversity is petitioning for protection of the world's largest seafloor species, bubblegum coral Paragorgia arborea.
Photo credit: Copyright Greenpeace/Malcom Pullman

big trees, big pieces of trees. They'd be attached to the rocks at the base" (Breeze et al. 1997). The trees in this case were most likely bubblegum corals (*Paragorgia* sp.) or red-tree corals (*Primnoa* sp.). Following the beginning of bottom trawling in this region, fishermen also noted that less and less coral was caught over time. The historical reports of deep sea coral bycatch suggest a need to be cautious when interpreting current deep sea coral distributions, as we have not been witness to changes in the distribution pattern over time from cumulative fishing impacts (i.e., the Shifting Baseline phenomenon, Pauly 1995).

that different coral species occupy different niches based on preferences for different current flows.

Despite growing knowledge of deep sea coral distributions, the vast majority of the seafloor has not been surveyed for deep sea corals. Thus, an important factor in our current knowledge of deep sea coral distributions is where scientists have conducted research and why. Scientists suggest that the perceived abundance of *L. pertusa* in the northeast Atlantic is partly because of the intense scientific, economic, and military investigations that have occurred there (Freiwald 2003, Roberts et al. 2006). Other examples of activities that have incidentally aided in the collection of deep sea coral distribution data include exploration in Hawaii for precious corals used in jewelry trade, discoveries in the Gulf of Mexico as a byproduct of deep sea research, and bycatch of corals in fisheries. Along the Pacific coast of North America, most deep sea coral records come from research-trawl surveys and bycatch records from fisheries (Etnoyer and Morgan 2003, 2005). Since these early discoveries, many of the same areas have been surveyed by remotely operated vehicles (ROVs) or manned submersibles.

In some cases, however, we should be circumspect about the data we are relying on. Regional knowledge of deep sea coral distributions may vary considerably. For example, fishermen have long known about some deep sea corals from bringing them up in their nets, but scientists have only recently described many others. For those areas that have been historically impacted by fisheries, we will never have baseline information on pre-impact coral distributions (see Box 2.1). Watling and Auster (2005), who produced the most comprehensive review of gorgonian coral records in the New England and Mid-Atlantic regions, state that records have been collected largely opportunistically and sporadically. Etnoyer and Morgan (2003, 2005) classified Pacific deep sea coral records into 4 categories reflecting the degree of expertise associated

The red gorgonian (*Lophogorgia chilensis*)
Photo credit: Shane Anderson

"Bottom trawling is simply not sustainable. The trawl nets are stripping the seabed of life, trashing ancient corals and destroying entire ecosystems. There is much that we are still to learn about life in the oceans. Sadly, much of it will be gone before we get the chance if we don't act now."

Dr Sylvia Earle, Executive Director of Conservation International's Global Marine Division and Explorer-in-Residence at the National Geographic Society

with the coral identifications. Many corals collected from government trawl surveys or recorded on video are difficult to identify beyond the family level, and some survey programs lack the assistance of experts in coral taxonomic identification. The shortage of trained coral taxonomists is a worldwide problem that hinders our understanding of coral distribution (Cairns 2001).

Stony Corals (Scleractinia)

The generic term "coral" is most often applied to stony corals that form hard, calcium-carbonate skeletons. Of the nearly 500 species of stony coral in the deep sea, only 6 or 7 species grow into mounds that resemble the more familiar tropical reefs (Cairns 2001, Freiwald et al. 2004). Although superficially similar to tropical coral reefs, deep sea coral reefs are composed of only 1 or 2 framework species, in contrast to the large diversity of species that comprise tropical reefs. As coral colonies expand, the space between the coral branches is eventually filled with trapped sediments, and the base of the colony becomes a mound of unconsolidated sediment trapped in a dead coral framework, with living corals growing on the outside. While these structures are often described as reefs, scientists refer to them as bioherms. If, over time, the sediment consolidates into a concrete-like crust (a process called lithification) the formation is referred to as a lithoherm (Neumann et al. 1977).

There are 2 major reef-forming species of stony coral in the USA: *Oculina varicosa* and *Lophelia pertusa*. Other stony coral species, such as *Enallopsammia profunda* and *Madrepora oculata*, contribute to the reef framework in some places. *O. varicosa* has slender white branches and can reach up to 7 ft in height. It is often difficult to distinguish individual colonies on mature reefs since they combine over time to form tangled thickets of mixed live and dead coral. *O. varicosa* inhabits relatively shallow coastal waters from

North Carolina to the Caribbean Sea (Reed 2002a), but at deeper depths (230 to 330 ft) off eastern Florida, it forms a nearly contiguous coral bank 103 miles long, with ridges and pinnacles up to 115 ft high (Reed 2002a).

Lophelia pertusa, which is common in the Atlantic and rare in the Pacific, has a similar morphology to *O. varicosa* and also may develop into massive reefs (Figure 2.2). In the US Atlantic *L. pertusa* is distributed from North Carolina to Florida and into the Gulf of Mexico. *Lophelia* reefs rise up nearly 500 ft from the seafloor and live at depths between 1,300 and at least 3,000 ft (Reed 2002a). It has been estimated that the Blake Plateau, especially between southern North Carolina and Cape Canaveral, Florida, contains thousands of coral mounds, most of them unexplored (Paull et al. 2000, Reed 2002a). Significantly, deep sea coral reefs are unknown in the US Pacific, although small specimens of *L. pertusa* have been collected (Etnoyer and Morgan 2003). Recently, a small, isolated patch of *L. pertusa* was discovered by an ROV off the coast of Washington at a depth of 890 ft (Hyland et al. 2005). Scientists speculate that the presence of *L. pertusa*, but the absence of reefs, in the North Pacific may be related to sea water chemistry conditions that are unfavorable for reef building (Guinotte et al. 2006).

E. profunda often co-occurs with *L. pertusa* in waters from South Carolina to Florida (Reed 2002a, S.W. Ross unpublished data). *M. oculata* occurs from North Carolina to Florida and is also found in the northern Gulf of Mexico along the seaward edge of continental shelf (Schroeder et al. 2005). Other stony corals that may form bioherms in US waters include *Solenosmilia variabilis* and *Pourtalosmilia conferta* (Stephen Cairns, National Museum of Natural History, Washington D.C., pers. comm.).

Gold Corals (Zoanthidea)

Members of the order Zoanthidea are colonial, sea-anemone-like organisms. Gold corals are in the genus *Gerardia* and grow rigid branches that form bushy structures. They can grow up to 3.3 ft tall and 5 ft wide on lithoherms in the northeast Straits of Florida at 1800- to 1900-ft depths (Messing et al. 1990). The largest *Gerardia* reported was nearly 7 ft tall (Bell 1891, cited in Druffel et al. 1995). Gold corals are also found throughout the Hawaiian Archipelago, in beds off Oahu and Hawaii, and on the Cross Seamounts, and have been a target for the coral jewelry trade (Grigg 2002).

Gold corals, like other coral species, tend to occur in areas of increased current speed (Figure 2.3). In Hawaii they grow on ridges and walls (Parrish 2005), and off Florida they occur on the up-current portions of the crests of reefs (Messing et al. 1990).

Fig. 2.2: Large *Lophelia pertusa* bush off North Carolina at about 1,200 ft. Note squat lobster and sea urchin near bottom of photo
Photo credit: S.W. Ross et al., UNC-Wilmington

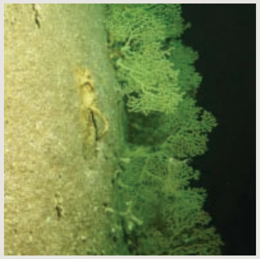


Fig: 2.3: Gold corals growing on a wall in the Northwestern Hawaiian Islands
Source: NOAA

Opposite page: Fly-trap anemone (Family Hormathiidae) on the slope of the Davidson Seamount (6,184 ft depth).
Photo credit: NOAA/MBARI

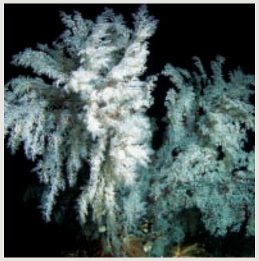


Fig. 2.4, Top: A white Christmas tree coral colony off southern California at 500 ft depth
Photo credit: M. Amend, NMFS

Bottom: Whip-shaped black coral off Florida
Photo credit: J. Reed, HBOI

Black Corals (Antipatharia)

Black corals—members of the order Antipatharia—are, deceivingly, not black in outwards appearance. The underlying skeleton is black or dark brown, but the color of the surrounding tissue varies across species and can be a range of brilliant colors including red, brown, orange, yellow, green, or white. Black coral polyps are only millimeters wide or even smaller, and they often form colonies in the shape of bushes, trees, or whips up to 8 ft tall (Figure 2.4). The skeletons of black corals are covered in thorn-like spines or knobs, and these corals are sometimes called thorny corals.

Antipathes dichotoma and *A. grandis* are 2 black coral species that have been collected for the jewelry trade off the main Hawaiian Islands at 130- to 250-ft depths (Grigg 2002). Black corals are also found along the Atlantic and Pacific Coasts, in the Gulf of Mexico, and on seamounts. Derickson Seamount (6,562-ft depth) and Denson Seamount (4,593-ft depth) in the Gulf of Alaska (Baco and Cairns 2005)[1] and Manning Seamount (5,577-ft depth) off New England[2] are just a few seamounts where black corals have been found.

Recently, scientists described a new species of black coral — the Christmas tree coral (*Antipathes dendrochristos*) off southern California (Opresko 2005). Despite growing to a height of over 8 ft and living just miles from one of the most densely populated urban centers in the world (Los Angeles), where there are many marine laboratories, this species remained undiscovered until 1995 (Tissot et al. 2006). As their name suggests, these coral colonies resemble Christmas trees, with extensive branching and ornaments of worms, barnacles, shrimps, and crabs. Researchers observed 135 colonies of these pink-, white-, red-, or gold-colored corals distributed at depths of 328–738 ft around the Channel Islands off southern California (Tissot et al. 2006).

[1] NOAA Ocean Explorer Gulf of Alaska 2004 Expedition: http://oceanexplorer.noaa.gov/explorations/04alaska/logs/aug05/media/coral_defense_video.html

[2] NOAA Ocean Explorer Mountains in the Sea 2004 Expedition: http://www.oceanexplorer.noaa.gov/explorations/04mountains/logs/may16/may16.html

Gorgonian Corals (Alcyonacea)

Gorgonian corals, also sometimes referred to as sea fans, have a flexible internal skeleton that allows some species to bend and sway in the currents like the branches of a tree in gusty winds. Gorgonian coral morphology is very diverse; some colonies have dense branches, grow several feet tall, and form groves, while others look like isolated whips or stalks standing upright on the seafloor. All gorgonian corals are members of the group Octocorallia, meaning that each polyp contains 8 tentacles. They are found throughout US waters, from continental shelf breaks and submarine canyons to isolated seamounts. Our focus is on those structure-forming species with erect, bush-like shapes; these species fall predominately into 4 families: red or pink corals (Coralliidae), bamboo corals (Isididae), bubblegum corals (Paragorgiidae), and red-tree corals (Primnoidae).

Red or pink corals, belonging to the family Coralliidae, are often referred to as precious corals because they have been used in jewelry since antiquity. Today several species are collected for the jewelry trade (as are some black corals, gold corals, and bamboo corals). Pink coral (*Corallium secundum*) and red coral (*C. lauuense*) are 2 species of Coralliidae found in Hawaii (Grigg 2002, Baco and Shank 2005). Corals in this family also occur on seamounts in the Gulf of Alaska (Baco and Shirley 2005, Heifetz et al. 2005), on Davidson seamount off California (deVogeleare et al. 2005), and on New England seamounts.[3] Their colonies are generally less than 2 ft in height, with a loosely spaced, rigid branching structure.

Bamboo corals in the family Isididae are so named because their skeletons resemble bamboo, with white, bony, calcareous sections separated by black internodes composed of protein (Figure 2.5). However, live colonies with extended feeding tentacles lose their resemblance to bamboo as they take on the red, orange, or white color of the polyps and outer tissue. Bamboo corals can grow in the shape of a branching bush or a single long whip up to 10 ft tall or more.[4] Bamboo corals occur along the East, West, and Gulf Coasts of the USA, in Hawaii, and on seamounts. Some bamboo corals are bioluminescent, emitting blue light when disturbed.[5]

In the family Paragorgiidae, the bubblegum coral (*Paragorgia arborea*) (Figure 2.6) is found primarily in the temperate regions of the USA in both the Atlantic and Pacific Oceans. It is found in submarine canyons and seamounts in the Gulf of Maine (Watling and Auster 2005), on seamounts in the Gulf of Alaska, around the Aleutian Islands in Alaska (Heifetz et al. 2005), in Hawaii, and along the US West Coast (Etnoyer and Morgan 2003). Colonies reaching 33 ft in height have been reported in New Zealand (Smith 2001), whereas in Alaska they seldom grow larger than 7 ft.[6] Bubblegum coral can be white or red, with characteristic round knobs throughout the colony.

Gorgonian corals in the family Primnoidae are usually tree-like or bushy with pinnate branches. Species of this family are found throughout the USA. Colonies of the red-tree coral (*Primnoa resedaeformis*) grow to 10 ft tall and 23 ft wide in Alaska (Krieger and Wing 2002), and have been known to fishermen in the Gulf of Maine since the 1800s (Watling and Auster 2005).

[3] NOAA Ocean Explorer Mountains in the Sea 2003 Expedition: http://oceanexplorer.noaa.gov/explorations/03mountains/logs/jul16/jul16.html

[4] NOAA Ocean Explorer Mountains in the Sea 2004 Expedition: http://www.oceanexplorer.noaa.gov/explorations/04mountains/logs/may12/may12.html

[5] NOAA Ocean Explorer Gulf of Alaska 2004 Expedition http://oceanexplorer.noaa.gov/explorations/04alaska/background/bamboo/bamboo.html

[6] NOAA Ocean Explorer Exploring Alaska's Seamount Expedition: http://www.oceanexplorer.noaa.gov/explorations/02alaska/logs/jul15/media/paragorgia.html

Fig. 2.5: Skeleton of bamboo coral from Warwick Seamount
Photo credit: NOAA OE

Fig. 2.6: Bubblegum coral in Alaska
Photo credit: A. Lindner, courtesy of NMFS

Black coral (Antipatharia) on the Davidson Seamount at 5,016 ft depth.
Photo credit: NOAA/MBARI

"Today's trawlers are capable of fishing deep-sea canyons and rough seafloor that was once avoided for fear of damaging nets. To capture one or two target commercial species, deep-sea bottom trawl fishing vessels drag huge nets armed with steel plates and heavy rollers across the seabed, plowing up and pulverizing everything in their path. For a few commercial target species, thousands of tons of coral are hauled up only to be thrown back dead or dying, along with huge quantities of unwanted bycatch. In a matter of a few weeks or months, bottom trawl fishing can destroy what took many thousands of years to create."

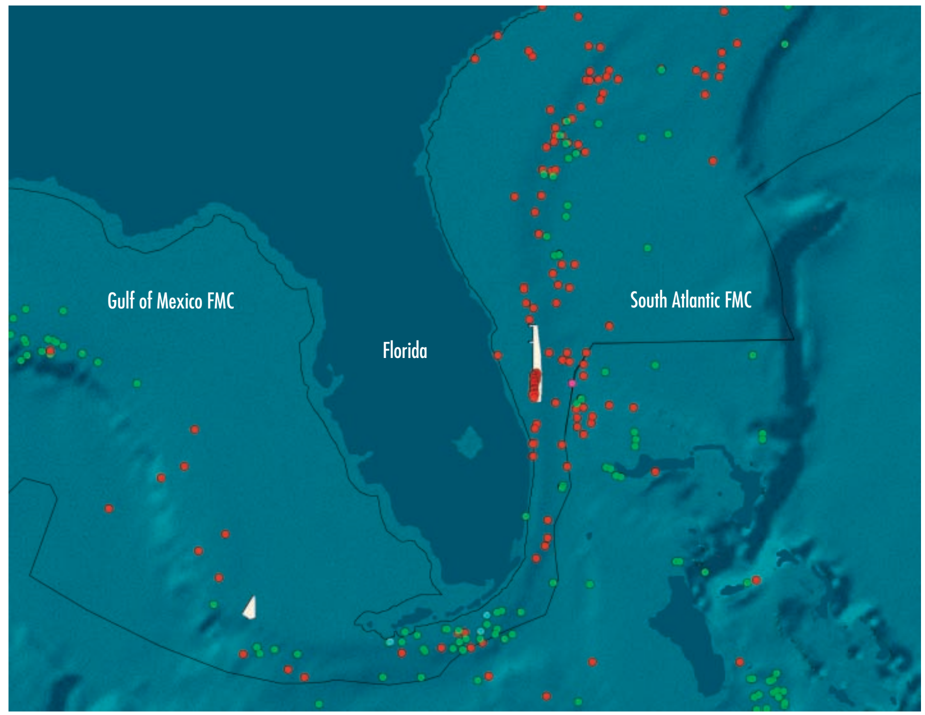
Deepsea Conservation Coalition April, 2006

Hydrocorals (Stylasterina)

Hydrocoral is the general term applied to corals in the orders Milleporina (tropical fire corals) and Stylasterina, within the class Hydrozoa. Stylasterines are typically quite delicate, with rigid but brittle calcium carbonate skeletons. As with other cnidarians they contain stinging cells, but the hydrozoan body plan is quite different from that of the other taxa of deep sea corals discussed in this report (which are in the class Anthozoa). Hydrozoan feeding and stinging polyps form groupings called cyclosystems, which are arranged in species-specific patterns over the surface of the skeleton and give hydrocorals a bumpy appearance superficially similar to the polyps of stony corals. There are several genera, but the genus *Stylaster* is one of the most common. Hydrocorals can be a variety of colors, including purple, orange, pink, and white. One of the largest species, *Stylaster cancellatus*, can grow to a height of almost 3.5 ft and is often densely concentrated (Wing and Barnard 2004).

Hydrocorals are distributed throughout the USA. The exceptionally high species diversity of hydrocorals in the Aleutian Islands—20 species or subspecies have been found in the island chain—has led to suggestions that this area may be an evolutionary center of origin for the group (Heifetz et al. 2005). Recent analysis reveals that hydrocorals evolved in the deep sea and later moved into shallow water, a unique pattern not documented in other marine species (Lindner 2005).

Off the east coast of Florida and along the southwest Florida shelf, hydrocorals are common in some locations (Reed et al. 2005b). They are one of the most abundant taxa on lithoherms in the northeast Straits of



Map 3: Waters of the southeastern USA are home to many taxa of deep seal corals. The Oculina *Bank HAPC (white area) off the east coast of Florida is closed to bottom fishing to protect deep sea corals. Corals: ● stony corals, ● gold corals, ● gorgonian corals, ● hydrocorals. HAPC. Black line is US EEZ.*

Florida, occurring at densities of over 8 to 10 colonies per yd^2 (Messing et al. 1990). Further south and west, on the bioherms of the Pourtales Terrace, there are dense fields of hydrocorals, growing to heights of 10 inches, and reaching concentrations of up to 96 colonies per yd^2 (Reed et al. 2005b).

Deep Sea Coral and Sponge Assemblages

Coral colonies of the same species often form nearly exclusive groupings, with representatives of other corals present at lower densities. However, in some cases deep seafloor assemblages can contain a wide diversity and abundance of sponges and deep sea corals. For example, the waters of the southeastern USA, from Georgia to South Carolina, and along the Florida-Hatteras slope, contain many taxa of deep sea corals (Map 3). In many places sponges, gorgonian corals, and black corals are found at high densities within *Lophelia* reefs (Reed 2002a, S.W. Ross et al. unpublished data). Many sponges and gorgonian corals are found within hydrocoral-dominated coral gardens of the Aleutian Islands (Figure 2.7), and black corals are often seen in fields of bamboo coral in the Gulf of Mexico (S. Brooke, U. Oregon, pers. comm.).

Sponges are an important component of most deep sea coral ecosystems and their abundance and diversity can equal or exceed that of the corals. Glass sponges (Hexactinellidae) are a diverse group of sponges found in the deep sea. With the recent expansion of research into deep sea coral habitats, scientists have discovered an astounding variety of sponges, including many new to science (Lehnert et al. 2005). However, we still know virtually nothing about the biology and ecology of these significant components of deep sea coral ecosystems.

Summary

This report focuses on 5 taxa of deep sea corals found in US waters: stony corals, gold corals, black corals, gorgonian corals, and hydrocorals. They come in various shapes and sizes, from massive reefs miles long to single bush-shaped individuals many feet tall. Our understanding of their distribution is currently limited and varies greatly by region. Because of differences in data collection, it is difficult to compare coral distributions from one region to the next. The quantity of data available may be significantly biased toward those geographic areas and depth zones where fishing or oil and gas exploration and development activities occur.

The vast majority of the seafloor has not been surveyed for deep sea coral occurrences. Present data show that deep sea corals are widely distributed, but are often very localized in their concentration. They are generally found in areas with hard seafloor substrates and appropriate currents, such as the seaward edge of the continental shelf (an area also know as the shelf break), around the edges of submarine canyons, and on offshore banks and seamounts.

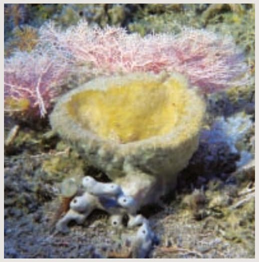


Fig. 2.7, Top: Sponge-gorgonian coral assemblage in Alaska
Photo credit: R. Stone, NMFS

Bottom: Hydrocoral (*Stylaster filogranus*) with Choristida vase sponge in the foreground at a southern Florida bioherm
Photo credit: J. Reed, HBOI

"Sponges are an important component of most deep sea coral ecosystems and their abundance and diversity can equal or exceed that of the corals"

A number of human activities pose a threat to deep sea corals. Most of these activities are poorly known due to insufficient study and lack of adequate monitoring.

Threats to Deep Sea Corals

Despite their diversity, all deep sea corals share an important characteristic—their vulnerability to human activities that damage the seafloor or alter the deep ocean environment (Freiwald et al. 2004, Guinotte et al. 2006, Kahng and Grigg 2005, Roberts et al. 2006, Rogers 1999). These activities threaten the health and survival of deep sea corals worldwide:

- Fishing, especially bottom trawling
- Oil and gas exploration and extraction
- Coral exploitation and trade
- Introductions of invasive species
- Increasing atmospheric CO_2
- Cable laying
- Waste disposal
- Mineral extraction
- Bioprospecting

Bottom Trawl Fishing

In recent years, many reports have documented the impacts of different fishing methods on seafloor habitats (Barnes and Thomas 2005, Benaka 1999, Kaiser et al. 2006, National Research Council 2002). Bottom trawl fishing gear, which targets fish living on or just above the seafloor, breaks and smashes deep sea corals (Fosså et al. 2002, Hall-Spencer et al. 2002, Puglise et al. 2005). Damaged colonies that do survive bottom trawling may be unable to successfully reproduce (Waller and Tyler 2005). Large bottom trawling gear can weigh several tons (Merrett and Haedrich 1997), and the groundline, which keeps the net in close contact with the seafloor, is often weighted and modified with large, heavy discs, tires, or rollers designed to ride over, or break through obstructions and keep the net from snagging and tearing on the seafloor (Figure 3.1). The damage caused by bottom trawling has been compared to forest clear-cutting (Watling and Norse 1998), and it is considered by scientists, managers, and fishing professionals to be the most ecologically destructive fishing method (Chuenpagdee et al. 2003, Morgan and Chuenpagdee 2003).

Because bottom trawling occurs all over the world, there are many international examples of coral damage caused by this fishing

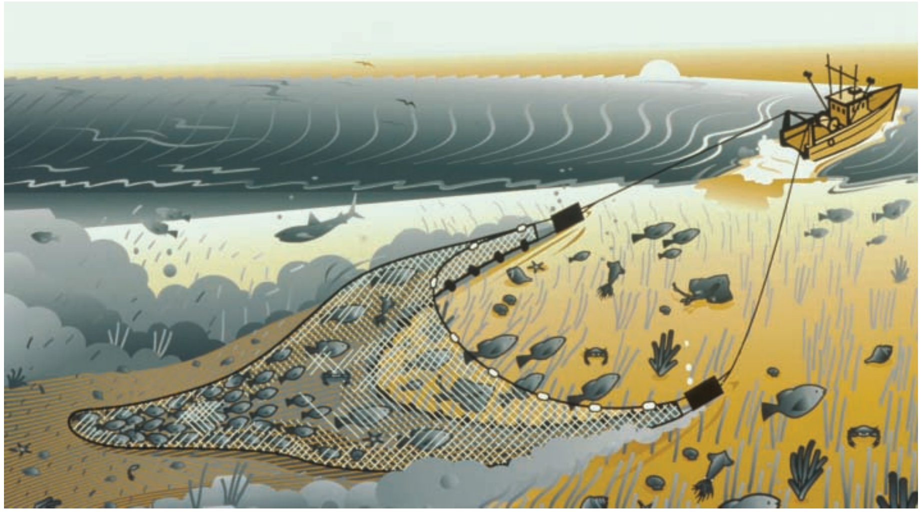


Fig. 3.1: Depiction of bottom trawl gear as it drags along the seafloor damaging everything in its path.

Black coral (*Trissopathes* sp.) and deep sea octopus on Davidson Seamount at 6,510 ft depth
Photo: NOAA/MBARI

"The most notorious non-selective equipment includes nets large enough to envelop twelve 747 airliners and capable of catching up to 200,000 pounds of fish at each setting; and lines up to 80 miles long that carry some 3,000 hooks."

United Nations Earth Summit + 5, June 1997

*Opposite page: The California hydrocoral (*Stylaster californicus*) at Point Lobos often had purple or red sea urchins (shown here *Strongylocentrotus franciscanus*) associated with them.*
Photo credit: Steve Lonhart/MBNMS

> **"At present, scientists studying deep-sea corals are in an unfortunate race with commercial fishermen, who are trawling these corals into oblivion."**
>
> *–Dr Martin Willison, Dalhousie University, Halifax*

Untrawled

Figure 3.2a: Untrawled *Oculina* reefs.
Groupers were abundant on deep sea *Oculina* reefs off Florida before trawling began; legal and illegal trawling has nearly eliminated the corals and large fishes in this ecosystem

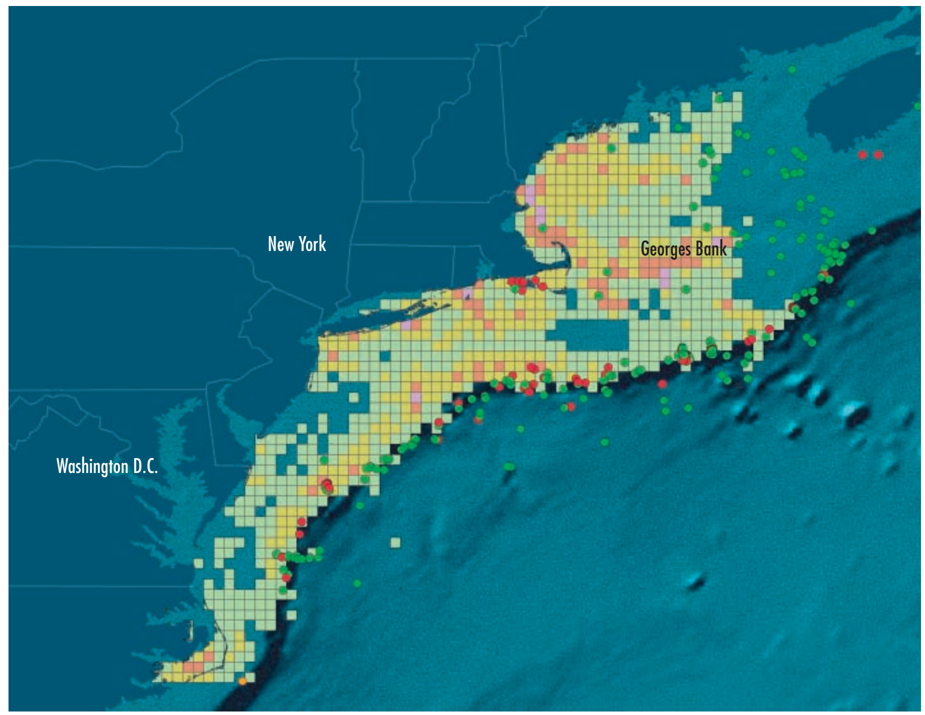
Photo credit: R.G. Gilmore

Trawled

Figure 3.2b: Trawled *Oculina* reefs.

Photo credit: L. Horn, NURC/UNCW

method. In Norway, 30 to 50% of pre-existing *Lophelia* reefs have been destroyed by trawling (Fosså et al. 2002). Trawl damage to *Lophelia* reefs in Irish waters has also been documented (Hall-Spencer et al. 2002). Bottom trawling that occurs in Atlantic Canada breaks deep sea corals that inevitably end up in fishing nets (Mortensen et al. 2005). Canadian fishermen have observed a decrease in deep sea corals over time, suggesting that corals have been removed by fishing and are not recovering (Gass and Willison 2005). In the southern hemisphere, trawling has reduced coral coverage on one Tasmanian seamount from 90% to 5% (Koslow et al. 2000). In just a single hour of trawling for orange roughy, trawlers off New Zealand removed 1.6 tons of corals (Anderson and Clark 2003).

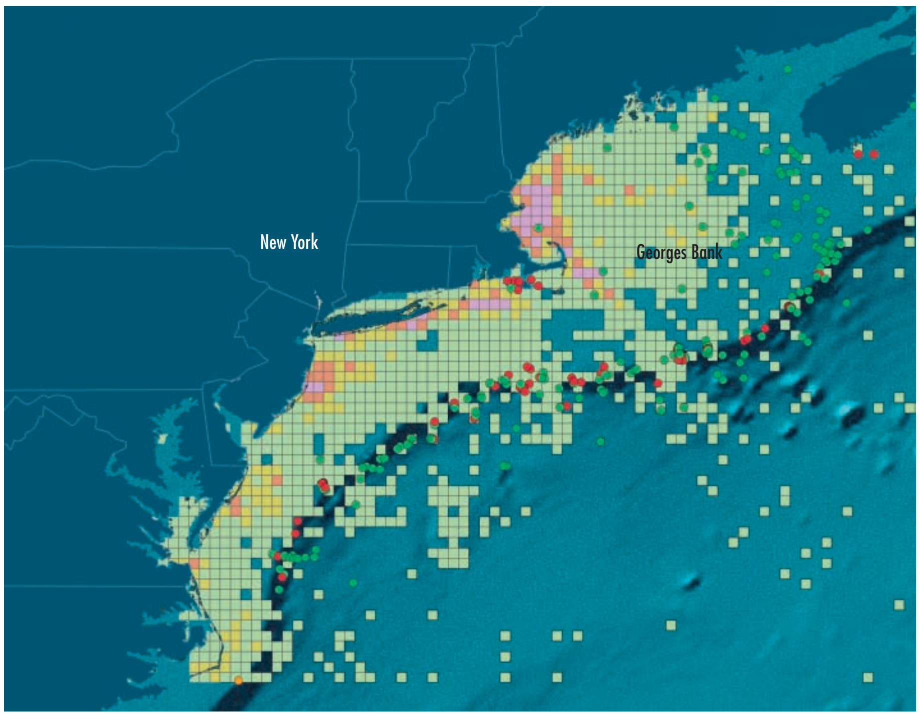


Map 4a: Deep sea corals and fishing intensity by bottom trawl in the New England and Mid-Atlantic fishery management council regions. Total bottom trawl trips for the years 1995–2001: ■ 51–389, ■ 390–993, ■ 994–2045, ■ 2046–5172 Corals: ● stony corals, ● gorgonian corals.

In the USA, fishing is the most widespread activity directly impacting deep sea corals. In recent years, managers and conservation organizations have begun to analyze the spatial overlap of fishing and deep sea coral distributions (Morgan et al. 2005). However, the detailed data required to conduct these studies are difficult to obtain and are often of insufficient quality for rigorous analyses. One of the largest hurdles in protecting deep sea corals is the incomplete knowledge of their distribution and threats. Here, we review the spatial overlap of available coral distribution and fishing intensity data by region (see Map 1 for the extent of the 8 regions). We obtained fishing data from the National Marine Fisheries Service (NMFS), but in many cases, detailed data on fishing locations were withheld in order to protect the confidentiality of fishermen. Through government and museum efforts and data mining by Etnoyer and Morgan (2003) and Watling and Auster (2005) some regional deep sea coral datasets have been made readily available (see Appendix).

New England and Mid-Atlantic Regions

The fishing grounds in the New England and Mid-Atlantic regions (Map 4a, 4b) have been heavily exploited for centuries, although trawling was not intensive until the last half of the 20th century. Fishing intensity varies throughout this region and across gear types. However, bottom trawling gear is the most widely used fishing gear (Map 4a, previous page). A 1996 study estimated that the entire Georges Bank seafloor is trawled 3–4 times annually (Auster et al. 1996). Georges Bank is the main New England fishing ground, located approximately 60 miles offshore. It is



Map 4b: Deep sea corals and fishing intensity by bottom gillnet trips in the New England and Mid-Atlantic fishery management council regions. Total bottom gillnet trips for the years 1995–2001: ■ 1–75, ■ 26–275, ■ 276–750, ■ 751–3831 Corals: ● stony corals, ● gorgonian corals.

Black coral on New England seamount
Photo credit: Deep Atlantic Stepping Stones Science Team/ IFE/URI-IAO/NOAA

Rosy rockfish (*Sebastes rosaceus*)
Photo credit: Chad King/MBNMS

Callogorgia americana with a newly discovered species of ophiuroid (*Asteroschema* sp.) in the Gulf of Mexico.
Photo credit: S. Brooke et al. courtesy Minerals Management Service.

oval in shape, and measures approximately 150 by 75 miles — slightly larger than the state of Massachusetts. Corals have been recorded in this region since 1874 (Watling and Auster 2005, Yale Peabody Museum[1]), but scientists suspect that the distribution of deep sea corals observed today has been altered by bottom fishing, and that many of the corals in historical records have since been destroyed by fishing (Watling and Auster 2005).

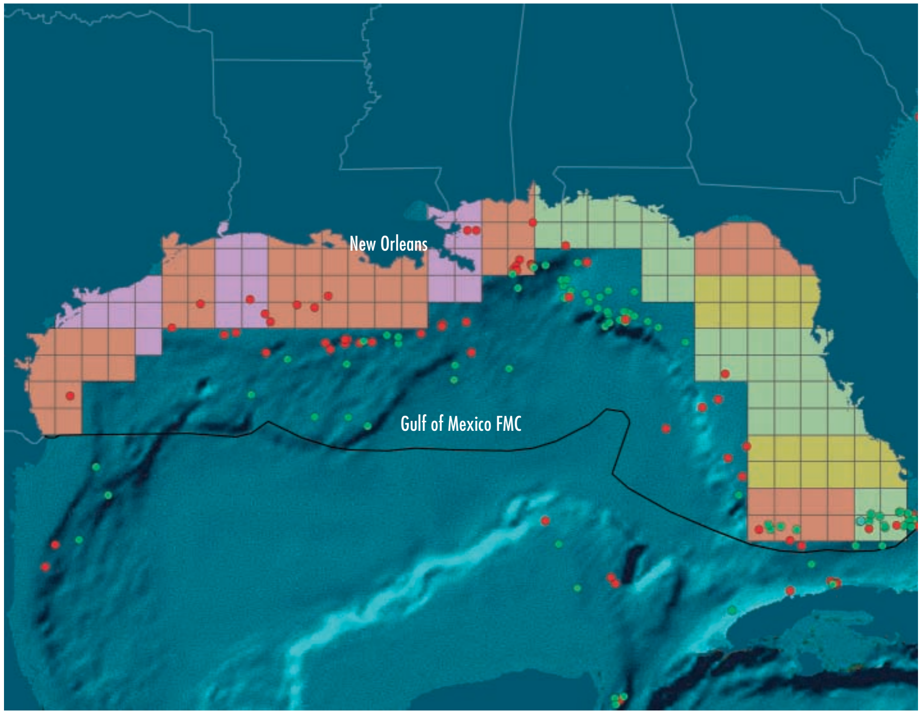
South Atlantic Region

In the US South Atlantic region, bottom trawls are widely used in shallow waters along the continental shelf to catch shrimp, but only in Florida does the trawl fishery for rock shrimp significantly interact with deep sea coral reefs. Currently there is little other commercial bottom trawl fishing that could impact corals. The *Oculina* Banks, a series of coral mounds that stretches for some 100 miles along the eastern coast of Florida, is the best known, most significantly degraded deep sea coral habitat in US waters. Since the 1970s, live *Oculina varicosa* coral cover in the 122 mi^2 Experimental *Oculina* Reseach Reserve has been reduced by over 90%; by far the greatest cause of this devestation has been bottom trawling (Koenig et al. 2005, Reed et al. 2006) (Figures 3.2a and 3.2b, page 28).

[1] Peabody Museum Invertebrate Zoology Collection: http://www.peabody.yale.edu/collections/iz/

Gulf of Mexico Region

In the Gulf of Mexico, there is some cause for concern over bottom trawl fisheries that target shrimp. Bottom trawling for royal red shrimp is potentially problematic because it can occur to depths of 2,400 ft. Though this deep water shrimp fishery is very limited, just one trawl pass can result in decimation of a deep sea *Lophelia* reef. In general,

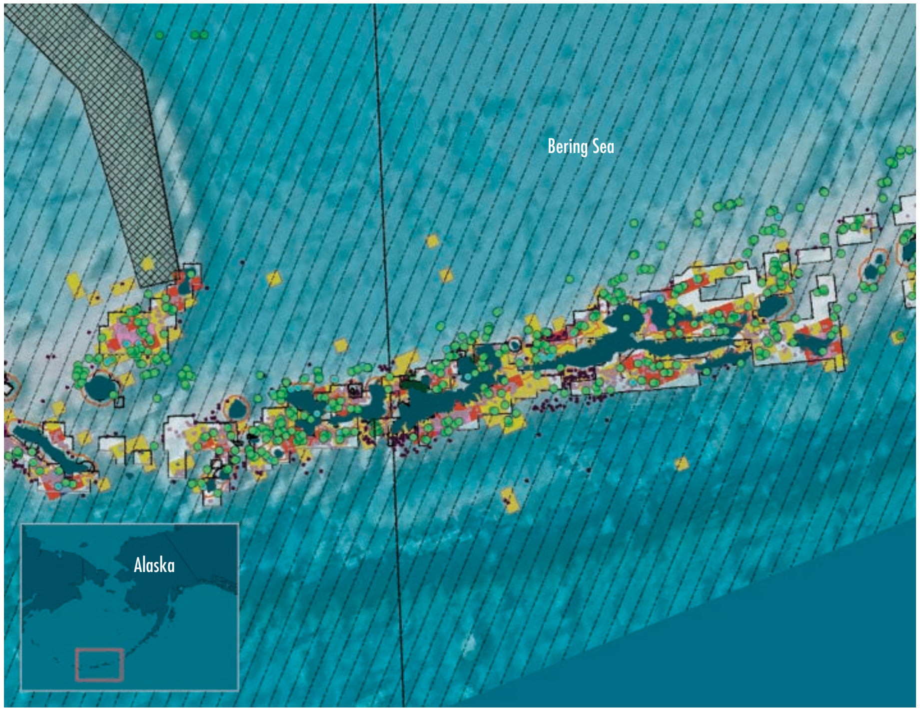


Map 5: Deep sea coral occurrences and bottom trawl intensity data from NMFS for the Gulf of Mexico. Shrimp (total tons) years 2001–2004: ■ 320–2500, ■ 2501–5000, ■ 5001–30000, ■ 30001–55862 Corals: ● stony corals, ● gorgonian corals, and ● hydrocorals. Black line is US EEZ.

it is difficult to assess the impact of fishing in this region because the NMFS data from the shrimp trawl fishery are summarized into large spatial blocks that are too coarse relative to known deep sea coral locations (Map 5).

Caribbean Region

The Caribbean region includes the EEZ waters of Puerto Rico, US Virgin Islands, and Navassa Island (an uninhabited US territory located between Haiti and Jamaica). No active bottom trawl fisheries occur in this region. Thus far, few occurrences of deep sea corals are known from this region, and therefore no management is in place for their protection. However, several major structure-forming coral species have been observed in the region, including *Enallopsammia rostata*, *Lophelia pertusa*, *Maderopora carolina*, *Madrepora oculata* (Ginsberg and Lutz in prep.), and these observations hint at the presence of deep sea banks or lithoherms.



Map 6: Bottom trawl closures in the Aleutian Islands (hatched areas) prevent the further expansion of the fishing fleet, but intensive trawl fishing continues in areas with deep sea corals (non-hatched areas). Observed bottom trawl trips, 2001–2003: ■2–10, ■ 11–50, ■ 51–100, ■ 101–250, ■ 251–682. ▧ Bowers Ridge Habitat Conservation Zone, ▨ Aleutian Islands Habitat Conservation Area, Corals: • hydrocorals, • gorgonian corals.

North Pacific Region

In the North Pacific region, bottom trawling is intense in the Bering Sea and Aleutian Islands and to a lesser extent in the Gulf of Alaska. Between 1997 and 2001, an average of 81.5 tons of coral was uprooted every year by commercial fishing in the North Pacific; 97% of this was attributed to bottom trawls (NMFS 2004, North Pacific Fishery Management Council 2003). In the Aleutian Islands, there is an extraordinary diversity of deep sea corals; among the 69 known species and subspecies of corals there, 25 are endemic—found nowhere else in the world (Heifetz et al. 2005). Bottom trawl fishing targeting Atka mackerel and a variety of rockfishes overlaps with deep sea coral occurrences in the Aleutian Islands (Map 6). One cause

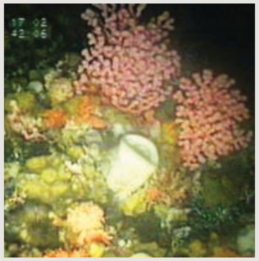


Fig. 3.3a, Top: An intact coral-sponge ecosystem in the Aleutian Islands.
Fig 3.3b, Bottom: An area damaged by traps used for catching gold king crabs.
Photo credit: R. Stone, NMFS

of this overlap is that many deep sea coral records were reported by fishery observers documenting bycatch. Only recently have researchers begun to examine areas outside of historical fishing grounds for the presence of deep sea corals.

Pacific Region

Along the US West Coast from Washington to California, bottom fishing for groundfish species occurs on the continental shelf. While several gear types are used in this fishery, bottom trawling affects the largest area and leaves the largest ecological footprint (Morgan et al. 2005). In Monterey Canyon, the bottom trawl fishery occurs in areas with deep sea corals, but most of the coral records are from the continental shelf break, where fishing intensity is currently low (Morgan et al. 2005). Without historical coral distribution data it is difficult to know whether or not this pattern is the result of decades of fishing pressure on the shelf that may have removed deep sea corals and prevented them from maintaining established colonies.

Western Pacific Region

In US waters around Hawaii and other islands of the Pacific (Guam, Marinas, America Samoa and several additional islands) managed by the Western Pacific Fishery Management Council, bottom trawling and dredging are prohibited and therefore do not affect deep sea corals.

Other Commercial Fishing Gears

Other commercial fishing gears also pose a threat to fragile deep sea corals (Morgan and Chuenpagdee 2003, Morgan et al. 2005, Mortensen et al. 2005). All bottom tending gears have the potential to snag or break deep sea corals. In Atlantic Canada, fishing gears such as longlines and gillnets that target demersal fishes (e.g., halibut, cod, and monkfish) entangle and damage delicate deep sea gorgonian corals (Mortensen et al. 2005). These nets and lines are commonly weighted in order to stay on the seafloor, causing damage to corals, and during retrieval they are dragged along the floor, often snagging and breaking corals (Mortensen et al. 2005).

In the North Pacific FMC region, pots for crabs and fishes and longlines for cod may also damage corals (Stone and Wing 2001). Although bycatch from these gears is significantly lower than that from bottom trawls, crab pots are typically deployed on long lines and often snag corals on recovery, significantly damaging them (Figures 3.3a and 3.3b, previous page). Bottom longlines have been documented snagging and knocking over coral colonies in the Gulf of Alaska (Krieger 2001).

Off the east coast of Florida, longline gear was found entangling an *O. varicosa* colony at Sebastian Pinnacles, at a depth of 260 ft (Reed et al. 2005a). In the New England and Mid-Atlantic regions (Map 4b, page 29), bottom gillnet fishing overlaps with known deep sea coral locations (Watling et al. 2003).

Recreational Fishing

Deep sea coral reefs, such as the *Oculina* Banks and deeper *Lophelia* reefs off the southeastern USA and in the Gulf of Mexico, sometimes support a number of valuable sport fish species, especially large groupers and wreckfish. As the details of these reef locations are circulated and with the use of today's navigational electronics, these areas will see additional fishing pressure from sportsmen. This may result in entanglement by fishing line that can break off pieces of the coral.[2] Deep water hook-and-line fishing to 2,000 ft, also called deep-drop fishing, targets deep water snappers, groupers, and wreckfish that are found on *Lophelia* reefs and mounds (S. Lutz, pers. comm.).

Oil and Gas Exploration and Extraction

The exploration for and development of petroleum products involves drilling and construction on the seafloor, including the laying of pipelines. This results in permanent alteration to seafloor habitat and causes short-term resuspension of sediment, both of which are detrimental to deep sea corals (Freiwald et al. 2004). Disturbance arising from oil exploration and extraction includes drilling; anchoring; placement of pipelines; potential leakage of drilling fluids, muds, and chemicals; dumping of drill cuttings; and oil spills from platforms and pipelines. These activities can smother, contaminate, and remove corals and alter the local ecosystem through organic enrichment (Freiwald et al. 2004, Glover and Smith 2003). During the process of laying pipelines, ships use 4 heavy anchors in a stepwise progression that leaves a large footprint on the seafloor.

The Gulf of Mexico is the world's most active region for deep water drilling and as such is the region where deep sea corals are most vulnerable to damage by oil and gas development activities. Approximately 50 production platforms are operational at depths greater than 1,640 ft (Glover and Smith 2003), and the oil and gas industry has drilled wells at depths of almost 6,500 ft. Thus, oil drilling and production is taking place at depths where deep sea corals occur (Avent 2004). The northern continental shelf in the Gulf of Mexico is already densely covered by more than 6,000 oil platforms and pipelines (Map 7, next page). In fact, some coral colonies are surrounded by networks of pipelines. Coral communities growing on salt domes in the Flower Garden Banks, a National Marine Sanctuary in the northwestern Gulf, are within a mile of the nearest platform. As the need for energy supplies increases, oil and gas exploration will likely expand into deeper water (Glover and Smith 2003), potentially threatening vulnerable coral communities that thrive in high concentrations along the continental shelf break and slope.

In the Gulf of Mexico and US South Atlantic regions, expansion of liquefied natural gas (LNG) pipelines and terminals is also a potential threat to deep sea corals. The US

[2] Deep Treasure, Florida Sportsman, August 2005: http://www.floridasportsman.com/sportfish/grouper/050844/index.html, accessed April 5, 2006

A brittle star wraps its arms around the branches of a gorgonian coral colony (*Metallogorgia* sp).
Photo credit: the Deep Atlantic Stepping Stones Science Party, IFE, URI-IAO, and NOAA

Bubblegum coral (*Paragorgia* sp.) from Aleutian Islands, AK.
Photo credit: A. Lindner, courtesy of NMFS

*Opposite page: Bubblegum coral (*Paragorgia arborea*) 8 feet in height were not uncommon at the crest of the Davidson Seamount; here shown at 4,150 ft. Photo credit: NOAA/MBARI*

Department of Energy forecasts that by 2010, a terminal and pipeline supplying the Florida market will be constructed between the Bahamas and the east coast of Florida, potentially cutting across some important deep sea coral beds (Energy Information Administration 2003).

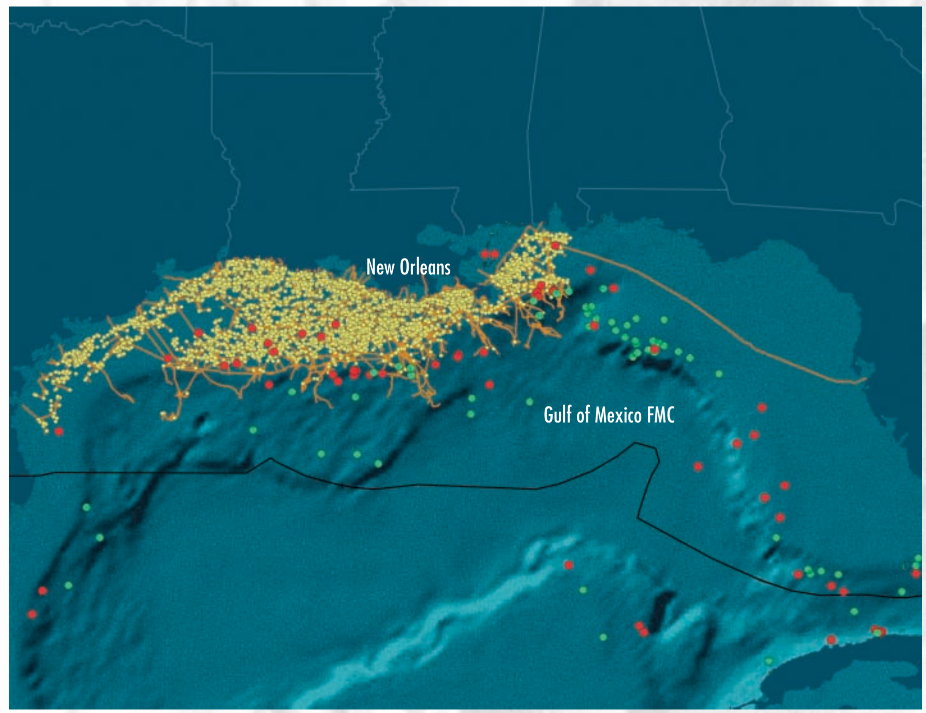
In the Pacific region, smaller-scale oil and gas activities occur off the southern California coast where a new species of deep sea coral — the Christmas tree coral — was recently described (Opresko 2005).

Throughout the waters of the USA, reserves of oil, gas, and minerals exist that may eventually be valuable enough to offset the cost of exploration and extraction. If current trends continue in the global oil and gas markets, other regions may come under pressure as the demand for energy grows and the USA looks to its own waters to supply these needs.

Coral Exploitation and Trade

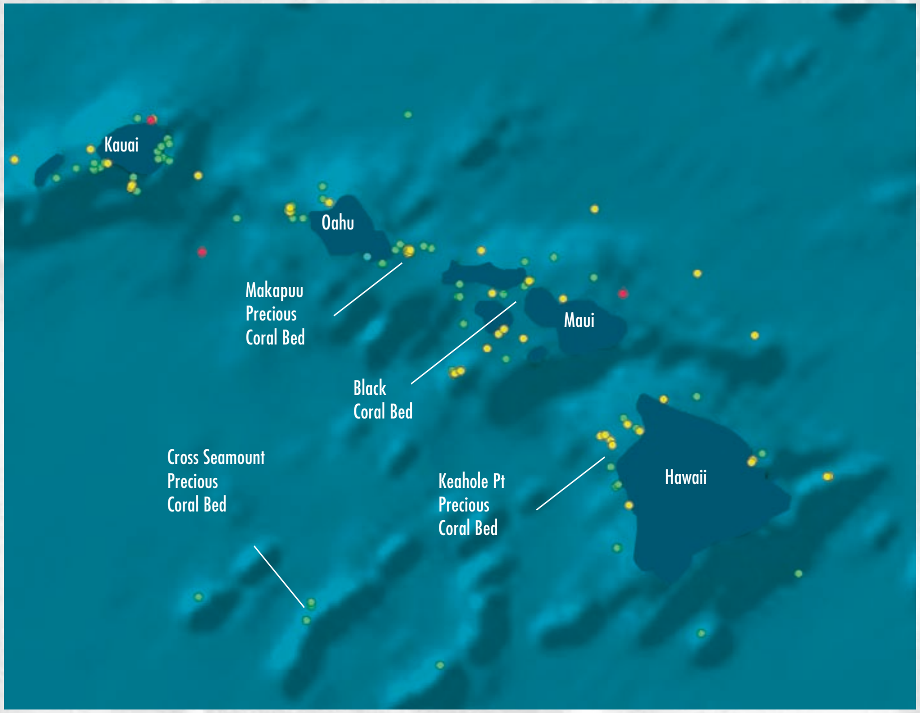
Several species of deep sea corals, including pink, red, bamboo, black, and gold corals, are collected for use in jewelry. These species are often referred to generically as precious corals. In the USA, precious coral collection occurs only in Hawaii (Map 8, Figure 3.4). Precious corals in shallower waters are typically collected by scuba divers, while deeper species are collected by manned submersibles, by remotely operated vehicles (ROVs), or by dragging iron bars and chains across the seafloor to break and ensnare corals. This last practice is highly destructive and unsustainable, and no longer occurs in US waters.

Pink corals were first discovered in Hawaii in 1900, and commercial exploitation began in the 1960s (Grigg 2002). Pink coral beds found on the Emperor Seamount at a depth of 1,312 ft supported a coral fishery for 20 years. During this period, corals were collected by dragging entangling gear along the seafloor, with up to 440,000 lbs of



Map 7: The northern continental shelf in the Gulf of Mexico is densely covered by oil and gas platforms and pipelines. ● platforms, – pipelines, ● stony corals, ● gorgonian corals. Black line is US EEZ.

corals collected annually by Japanese and Taiwanese fishermen (Grigg 2002). Another pink coral fishery operated in the 1970s off Oahu at a depth of 1,300 ft. Gold and bamboo corals were also discovered in 1970 and collected by manned submersibles and ROVs. Fishing for red, pink, and gold corals has been intermittent since 1999, owing to permit requirements, weather, and high costs. However, in the 1999–2000 season, 2,675 lbs of pink coral, 730 lbs of gold coral, and 134 lbs of red coral were collected in Hawaii (Grigg 2002). Hawaii also supports a fishery for black corals that started in 1958. The main black coral bed is found off Maui at depths of 130 to 250 ft. Between 1981 and 1997, an average of 2,235 lbs of black coral were collected per year. This fishery continues today, primarily conducted by scuba divers (Grigg 2001).



Map 8: Pink, red, bamboo, gold, and black corals have been collected in Hawaii for the jewelry trade. Corals: • stony corals, • black corals, • gorgonian corals, and • hydrocorals.

While there are no large-scale directed coral harvests at present, this may change with market forces. Deep sea corals, including precious corals, are not well studied, and a better assessment of their status is needed to shape collection guidelines. Recently the non-governmental organization SeaWeb petitioned the US Fish and Wildlife Service to request that the United States submit a proposal to include *Corallium* spp. in Appendix II of the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES) citing concerns over declining populations (P. Debenham, SeaWeb, pers. comm.).

Invasive Species

Introduced non-native species can invade the habitat of native deep sea corals, greatly reducing populations. Colonies of black corals in the Au'au Channel between the islands of Maui and Lanai are declining because of the invasion of the non-native snowflake coral (*Carijoa riisei*). This species was accidentally introduced to the Hawaiian Islands in

Fig. 3.4: Jewelry made of precious coral.

Photo credit: F. Tsao, MCBI

"If you wish, you can go to the middle of the ocean and fish on a seamount for any species, and you are accountable to no one—even if that destroys all of the fish and all of the corals and all of the sea life."

Dr. Michael Hirshfield, Oceana's chief scientist and North America vice president for policy

Opposite page: Lophelia pertusa *colony and squat lobster, Gulf of Mexico.*

Photo credit: S. Brook et al., courtesy MMS.

Fig. 3.5: White snowflake coral partially overgrowing an orange-colored black coral colony at a depth of about 311 ft in the Au'au Channel between the islands of Maui and Lanai in Hawaii.
Photo credit: HURL

"Key areas for protection are deep sea coral reefs and seamounts which are being strip-mined by bottom trawl fishing."

Simon Cripps, Director, Global Marine Programme, WWF

1972, probably by boats visiting Pearl Harbor from the Indo-Pacific, and has continued to spread throughout the main islands. It overgrows and smothers black corals in this region, most severely at depths of 260 to 340 ft. In one study, over 60% of all black corals observed were at least partially overgrown (Figure 3.5), and in some areas 90% of black corals had already been killed (Kahng and Grigg 2005).

Increasing Atmospheric CO_2

The oceans are changing both chemically and physically as a result of the carbon dioxide (CO_2) released from the burning of fossil fuels (Kleypas et al. 1999, Feely et al. 2004, Orr et al. 2005). Shallow water and deep sea corals and other marine species that need to build calcium carbonate skeletons will be harmed as oceans become more acidic.

Changing Seawater Chemistry

The influx of CO_2 to the atmosphere and uptake of CO_2 into the world's oceans is causing the sea to become more acidic. Corals and other marine organisms use carbonate ions from the surrounding water to build their skeletons and protective shells. As the oceans become more acidic, the calcification mechanisms of many marine organisms may be impaired, resulting in weaker skeletons (a process similar to osteoporosis in humans), slower growth rates, or both (Buddemeier and Smith 1999, Gattuso et al. 1999, Guinotte et al. 2003, Kleypas et al. 1999). Because deep sea corals also obtain nourishment from capturing plankton, some of which build calcium carbonate shells, these changes in seawater chemistry may also alter the productivity of coral prey (Riebesell 2004, Riebesell et al. 2000, Orr et al. 2005).

Warming Waters

Global temperatures are rising in the deep sea owing to an influx of anthropogenic CO_2 to the atmosphere (Barnett et al. 2005). Rising sea temperatures will probably influence deep sea coral calcification rates, physiology, and biochemistry, even though specific ranges and thresholds are not yet known. Changes in the salinity of the world's oceans as freshwater (ice melt) inputs to high-latitude waters increase may slow down water circulation, reduce upwelling, and alter current patterns (Bryden et al. 2005). These changes will probably alter surface productivity and the delivery of food to the seafloor, which could have a serious impact on the distribution of deep sea corals.

Other Threats

Additional threats to deep sea corals include cable laying, waste dumping and pollution, mineral extraction, and bioprospecting. The effects of these activities on deep sea corals have not been quantitatively studied, but their general impacts on the seafloor are discussed below.

Cable Laying

Installation of telecommunication and electricity cables on the seafloor requires digging a ditch for the cable to be buried in. This procedure and subsequent maintenance repairs will inevitably overturn organisms in the cable's path, resuspend sediment, and disturb the seafloor environment. Cables that are not buried deeply enough, or that are exposed, can be snagged and broken by fishing gears. Broken cables can sway on the seafloor with passing currents, causing continuous disturbance to the local environment (Freiwald et al. 2004).

Waste Disposal and Pollution

Various nations and international bodies have considered the deep sea as a disposal location for waste, including obsolete military ammunition, radioactive waste, sewage sludge, dredge spoil, and CO_2. However, significant waste disposal is not currently underway (Glover and Smith 2003). Leakage of contaminants, toxic substances, and heavy metals can pollute deep sea life. Increases in organic material can also pollute the deep sea and cause localized oxygen depletion that is sometimes fatal to deep sea organisms. CO_2 sequestration, the injection of CO_2 in liquid form to the deep sea, is under experimental study, and may expand in the coming decades to help dispose of greenhouse gases (Glover and Smith 2003). This process acidifies the seawater and alters water pressure at the disposal site, potentially affecting the health and changing the behavior of deep sea species (Glover and Smith 2003).

Mineral Extraction

Extraction of minerals from the deep sea is an expanding industry, targeting several kinds of minerals for multiple purposes. For example, manganese nodules and crusts are extracted for the cobalt, copper, and nickel that they contain, while polymetalic sulfides are taken for their gold and silver components. Methane hydrate extraction from the deep sea is being developed as an energy source. Most of these mineral resources are found in international waters, although further exploration is likely to occur in US waters. Commercial extraction is likely to increase in the next several decades (Glover and Smith 2003); damage to seafloor communities is an expected side effect at any mining site.

Bioprospecting

Bioprospecting removes coral colonies from the deep sea for biotechnology and pharmaceutical research and development. Collection of long-lived corals is a concern, but the amounts needed to analyze are usually small (1–2 lbs.). Bioprospecting in US waters currently only takes place in the South Atlantic Bight and Gulf of Mexico. Coral collection in these areas requires a permit and is overseen by the regional fishery management councils. It is unknown how other regions will regulate bioprospecting.

Summary

A number of human activities pose a threat to deep sea corals. Most of these activities are poorly known due to insufficient study and lack of adequate monitoring. Nevertheless, bottom trawling is the greatest current threat posed to deep sea corals because it takes place over extensive areas where corals occur.

Table 3.1: Examples of regional challenges in deep sea coral conservation

Region	Challenges
New England — Mid-Atlantic	Widespread bottom fishing
	Significant overlaps of trawl fisheries and deep sea corals
South Atlantic	Illegal trawling and poor enforcement of the *Oculina* Bank
	Continuing development of deep sea fisheries
	Recreational fishing targeting deep water species
	Potential LNG pipeline from Bahamas to Florida
Gulf of Mexico	Oil, gas, and LNG development
	Recreational fishing targeting deep water species
Caribbean	Lack of data
North Pacific	Significant overlaps of trawl fisheries and deep sea corals
	Other bottom fishing gears
Pacific	Significant overlaps of trawl fisheries and deep sea corals
	Oil and gas development off California
Western Pacific	Invasive species
	Precious coral trade
All regions	Baseline lack of scientific understanding
	Future energy exploration and development
	Insufficient fishing effort data for coral management
	Climate change
	Pollution

Current ocean management is insufficient to protect vulnerable and unique deep sea coral habitats. Fisheries management provides limited protection under existing laws.

Current Management of Deep Sea Corals

Throughout the world, many nations have recognized the value of deep sea corals and taken steps to provide them with greater protection. The European Union, Norway, Canada, New Zealand, and Australia have all taken steps to prohibit bottom trawling in certain coral areas. These actions range from comprehensive legislation in Norway, which now restricts trawling in known coral areas, to protection of some limited seamount areas in Australia and New Zealand, to fishing closures of relatively small known coral locations in Canada and the European Union. As of 2006, New Zealand is also considering a Benthic Protected Areas proposal that would prohibit bottom trawling and dredging in 31% of its waters, potentially protecting some key coral habitats.[1]

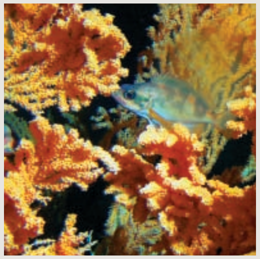
Within the 4.4 million mi^2 of ocean under US jurisdiction there are numerous species of deep sea corals. The US exclusive economic zone (EEZ) covers an area nearly 25% larger than the lands of the USA. The management of the US EEZ falls to multiple government agencies, most of them focused on either extraction or utilization of natural resources. Federal agencies in the USA with the authority to manage deep sea corals include the National Marine Fisheries Service (NMFS), in consultation with 8 regional fishery management councils (FMC); the National Marine Sanctuary Program (NMSP) of the National Ocean Service, both within the Department of Commerce, and the Minerals Management Service (MMS), in the Department of the Interior.

NMFS and the regional fishery management councils can protect corals by adopting regulations that restrict fishing gear types or access to fishing grounds. Until now, national marine sanctuaries have generally been designed to manage designated areas for multiple uses compatible with resource protection, but have in large measure deferred to NMFS and the regional councils in the management of fish and fish habitat within their borders (Chandler and Gillelan 2004). MMS oversees mineral and energy exploration and extraction in federal waters and is responsible for assessing the environmental impacts of these activities on natural resources, including deep sea corals, and limiting or mitigating these impacts. Despite increased research and mapping there is still a lack of dedicated research funding for deep sea corals. Conservation of deep sea corals is hampered by insufficient information, ongoing threats, weak management, insufficient legal mandates for protection, minimal enforcement, and insufficient penalties for resource violations.

NMFS and Regional Fishery Management Councils

Most legal protections for deep sea corals have been adopted in accordance with the Magnuson-Stevens Fishery Conservation and Manage-

[1] Deepwater Trawling: Navigating Troubled Waters. Clement and Associates Limited. February 2006: http://www.seafood.co.nz/doclibrary/news/DeepwaterTrawlingSolutions140206.pdf and World's largest EEZ marine conservation measure proposed. New Zealand Government Website. February 14, 2006: http://www.beehive.govt.nz/ViewDocument.aspx?DocumentID=24902



Juvenile sharpchin rockfish in a gorgonian red-tree coral community.
Photo credit: V. O'Connell, ADFG

"Everyone must be aware [that] without intact coral reefs, warm and cold water reefs, you will not be able to restore fish stocks fully."

Dr. Klaus Töpfer, Executive Director, United Nations Environment Programme (UNEP), World Oceans Day 2004

Opposite page: A gorgonian coral colony on a seamount off New England.
Photo credit: the Deep Atlantic Stepping Stones Science Party, IFE, URI-IAO, and NOAA

Box 4.1: Essential Fish Habitat and Habitat Areas of Particular Concern

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) requires fishery managers to designate essential fish habitat (EFH) in all federal fishery management plans. The MSA defines EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." The purpose of EFH is to identify areas required to support sustainable fisheries and ecosystems and to minimize adverse effects to the extent practicable. Habitat Areas of Particular Concern (HAPC) can also be designated and are defined by their important ecological function, sensitivity to human-induced degradation, degree of stress, and rarity of habitat type (Pautzke 2005). However, the MSA does not require protective regulations for EFH or HAPC, and the HAPC designation only signifies that the HAPC area is a higher priority for conservation.[2]

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[2] NOAA Office of Habitat Conservation: http://www.nmfs.noaa.gov/habitat/habitatprotection/efh/index_b.htm

ment Act (Magnuson-Stevens Act or MSA). Under the MSA, NMFS and the regional fishery management councils (see Map 1 for boundaries) are required to identify and minimize impacts on essential fish habitat (EFH) for each fishery (see Box 4.1 for explanation of EFH). However, the extent to which NMFS and the regional fishery management councils protect deep sea coral areas under the EFH provisions is highly variable. Some councils identify corals as a type of EFH for managed fish species, while others consider deep sea corals themselves to be managed species. Thus, some councils designate EFH specifically for deep sea corals, while others only include deep sea corals as EFH if a federally managed species can be shown to have a strong relationship with the corals. Often deep sea corals are not considered in EFH designations because councils have insufficient data on the location of corals in their regions, or they do not have sufficient information on the nature of the relationship between deep sea corals and managed fish species. Once an area is designated as EFH, the MSA does not require any specific protections to limit damage caused by destructive fishing practices, but NMFS is required to assess the adverse impacts of fishing (or other activities) and adopt protective measures to minimize bycatch of corals or crushing of corals by fishing gear.

National standard 9 of the MSA requires NMFS and the councils to adopt measures that "to the extent practicable, minimize bycatch and to the extent that bycatch cannot be avoided, minimize mortality of such bycatch." This applies to deep sea corals, and is a separate authority from EFH provisions. Below are the highlights of fishery management council actions to protect deep sea corals.

New England and Mid-Atlantic Regions

In the New England and Mid-Atlantic regions, the councils recently declared EFH for groundfish, and amended the fishery management plan to ban monkfish fishing using bottom trawls and bottom gillnets in Oceanographer and Lydonia Canyons on the southern edge of Georges Bank (Map 4). This affords some protection for deep sea corals, however, this ban does not cover bottom gears that target other fish. The monkfish fishery management plan amendment also limits rollers on bottom trawls in the monkfish fishery to a six-inch diameter in the southern half of the region. A pending proposal seeks to protect additional submarine canyons. In the Mid-Atlantic region Hudson Canyon contains deep sea corals, and is included in a habitat area of particular concern (HAPC) for tilefish, but there are no regulations to protect corals.

South Atlantic Region

In the US South Atlantic region, deep sea corals are considered managed species, and their designated EFH is defined as "hard substrate in subtidal to outer shelf depths" throughout the region. As early as 1984, the South Atlantic Fishery Management Council took steps to protect deep sea corals from trawling by establishing the *Oculina* Bank HAPC (Koenig et al. 2005). This 397 mi^2 HAPC off Florida now prohibits bottom fishing, but enforcement remains weak despite implementation of vessel monitoring in 2002.[3] Trawlers have fished illegally for rock shrimp in the *Oculina* Bank HAPC as recently as 2004,[4] and recreational fishermen frequent the still intact areas of the *Oculina* Bank (S. Brooke, U. Oregon, pers. comm.). Currently under development, the council's draft Comprehensive Fishery Ecosystem Plan Amendment would designate additional HAPCs for known areas of deep sea corals, including the *Lophelia* banks off Cape Lookout, Cape Fear, Stetson Reef, the Savannah and Southwest Florida lithoherms, Miami Terrace, and Pourtales Terrace.

[3] Amendment 5 of the Shrimp Fishery Management Plan, http://www.safmc.net/Library/Shrimp/tabid/413/Default.aspx

[4] Commercial and recreational fishermen fined for Oculina Bank violations. NOAA Fisheries news release, December 8, 2004: http://www.nmfs.noaa.gov/ole/news/news_SED_120804.htm

Gulf of Mexico Region

In the Gulf of Mexico, corals are considered a managed species. EFH and HAPCs have been designated for coral areas at shallower depths (< 660 ft) under the 2005 EFH amendment. Areas designated as HAPCs include Pulley Ridge, McGrail, Stetson, and East and West Flower Garden Banks, in addition to several small hard-bottom areas scattered on the northern shelf of the Gulf, and large hard-bottom areas off the west coast of Florida. Regulations to ban anchoring and the use of bottom trawls, bottom longlines, buoy gear, and traps and pots are being considered for some of the reef HAPCs. These regulations do not cover the known deep sea *Lophelia* reefs in the region. One additional regulation requires a weak link in the tickler chain of bottom trawls on all habitats throughout the Gulf of Mexico EEZ. The weak link is designed to break if the trawl net becomes hung up on uneven seafloor or snags on corals.

Caribbean Region

In this region corals are also a managed species. No active bottom trawl fisheries currently occur in this region. Deep sea corals, such as *Lophelia pertusa* and other stony corals, are known from this region, but no regulations are in place for their protection.

North Pacific Region

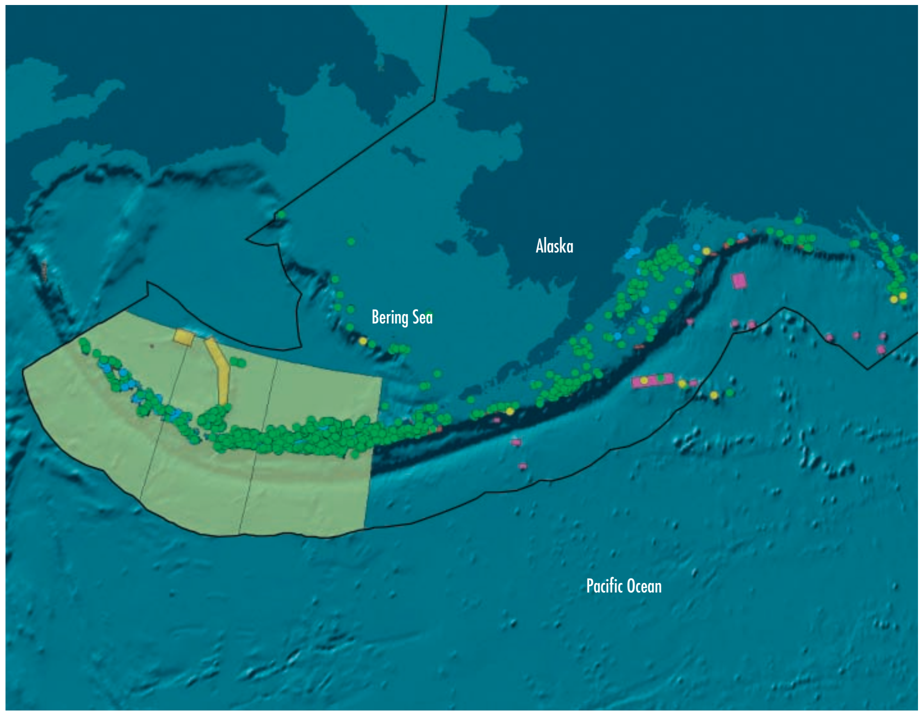
In Alaska, deep sea coral areas are considered essential fish habitat for groundfish (Witherell and Coon 2001). Deep sea coral and sponge areas have been designated as HAPCs for groundfish, and fishing is regulated by gear and location in order to protect deep sea corals. Around the Aleutian Islands, the 2005 EFH regulations prohibit bottom trawling in a 366,961 mi^2 area to address concerns about damage to seafloor habitat, particularly deep sea corals (Box 4.2, Map 9, next page). Additional protections for deep sea corals are in place in the HAPC at Bowers Ridge, where mobile bottom gear is prohibited, and in 6 small Coral Garden

Box 4.2: Freezing the Footprint of Bottom Trawling

In 2005, the North Pacific Fishery Management Council unanimously adopted an EFH amendment to close a 366,961 mi^2 area to bottom trawling. A similar strategy was also unanimously adopted by the Pacific Fishery Management Council for waters off California, Oregon, and Washington. In both of these cases the closures were put in place to prevent trawling from expanding into waters not yet fished. This has the effect of freezing the footprint of bottom trawling. It also reverses the burden of proof, requiring research to ensure that bottom trawling in an untrawled area is compatible with the habitat found in the area before fishing can be allowed. While preventing the expansion of bottom trawling is an important first step towards protecting deep sea corals, this measure does not protect corals from other fishing gears that can also snag and crush vulnerable coral colonies. Additionally most of the area closed to trawling is far too deep to be fished with current technology.

Marine Reserves (a total of 146 mi^2) closed to all bottom gears. Also, all fishing vessels in the Aleutians with bottom tending gear are required to carry a vessel monitoring system (VMS) device, which allows for better tracking of fishing effort and provides for better monitoring and enforcement of the closed areas.

In the Gulf of Alaska, a total of 20% of the seafloor is closed to bottom gear. The 2005 EFH amendment prohibits bottom trawling for groundfish in 10 areas thought to contain high-relief bottom and coral communities. Bottom gear is prohibited in all of the 16 named seamounts designated as HAPCs. Three areas of red-tree coral off southeast Alaska are also identified as HAPCs. The Southeast Alaska Trawl Closure prohibits bottom trawling, and the small (3.3 mi^2) Sitka Pinnacle Marine Reserve in southeast Alaska prohibits all bottom fishing and anchoring.



Map 9: Recent essential fish habitat designations by the North Pacific Fishery Management Council, including closures to bottom trawling. At this scale Aleutian Island Habitat Conservation Areas are misleading; significant coral areas are subject to bottom trawling in this region. See Map 6 for detailed view. ■ Aleutian Island Coral Gardens Marine Reserve, ■ Aleutian Island Habitat Conservation Area, ■ Alaska Seamounts Marine Preserve, ■ Bowers Ridge Habitat Conservation Zone, ■ Gulf of Alaska Habitat Conservation Area. Corals: ● black corals, ● gorgonian corals, and ● hydrocorals. Black line is US EEZ.

Pacific Region

In 2005, the Pacific Fishery Management Council designated EFH for groundfish species that will restrict bottom trawling in a number of regions including canyons, banks, and seamounts, including Thompson Seamount and Heceta and Daisy Banks. The EFH designation, partially approved by NMFS in 2006, will also place additional restrictions on bottom contact fishing gears in a number of areas, including Davidson Seamount and Cordell Bank. The action also freezes the current bottom trawl fishing footprint in waters between the depths of 4,200 and 11,500 ft (Map 10).

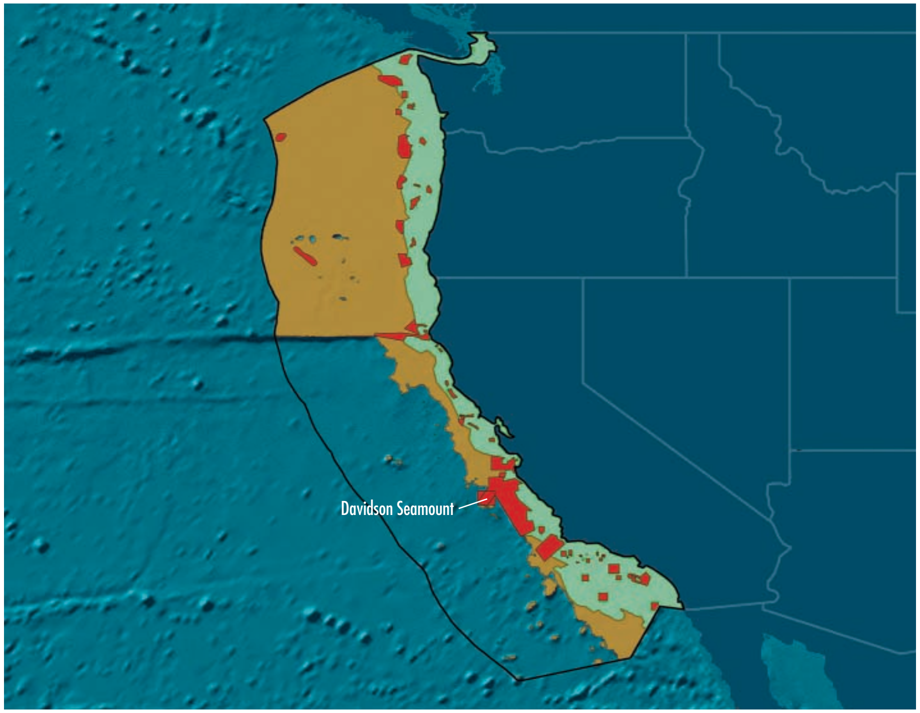
In addition to this management action, which is similar to that instituted by the North Pacific FMC, the Pacific FMC uses time and area closures to restrict fishing for groundfish species and allow them to recover from overfishing. In the Rockfish Conservation Areas, bottom trawling is prohibited; however, the boundaries vary by season and fishery, and are modified based on bycatch data reported by log books and fishery observers. In the 2 Cowcod Conservation Areas off southern California, trawling is prohibited year round. These closures potentially prevent trawl damage to corals, but they could also shift the intensity of trawling effort to coral areas that have not been as intensively fished. The potential of area closures to backfire provides a strong argument for freezing the footprint of bottom trawling as part of a comprehensive EFH plan.

Western Pacific Region

In 1986, bottom trawling and bottom gillnetting were prohibited by the Western Pacific FMC in all US-managed western Pacific waters to protect all types of coral (shallow and deep). Coral fisheries in the region are managed under a Precious Coral Management Plan that restricts non-selective gears such as tangle nets. There is no active fishing for precious corals in federal waters. Fishing for black coral occurs in the state waters of Hawaii. Should precious corals become more valuable in the future, a fishery may resume in federal waters.

National Marine Sanctuary Program

The National Marine Sanctuary Program manages 13 multiple-use sanctuaries (covering a total area less than 0.5% of the US EEZ) and the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve, which is being considered for sanctuary status. The Northwestern Hawaiian Islands Reserve likely has done the



Map 10: Recent essential fish habitat designations by the Pacific Fishery Management Council
■ Essential Fish Habitat (< 3,500 m), closed to bottom trawl gear, ■ Closed to all bottom gear, ■ Open to bottom gear
Black line is US EEZ.

The base of a living bamboo coral, *Isidella* sp., from Warwick Seamount. Notice the long tentacles, referred to as "hula skirts," because scientists don't know exactly what they are. They may be defensive "sweeper" tentacles.
Photo credit: Gulf of Alaska 2004 research team, NOAA OE

"At present, scientists studying deep-sea corals are in an unfortunate race with commercial fishermen, who are trawling these corals into oblivion."

Dr Martin Willison, Dalhousie University, Halifax

*Opposite page: The white ruffle sponge (*Ferrea *sp.) blanketed large areas, at or near the crests, of the Davidson Seamount (shown here at 4,593 feet depth). Several species were often found living on or within the sponge fields; including crabs; basket stars; sea stars; and brittle stars.*
Photo credit: NOAA/MBARI

most to protect corals, as a 2000 Executive Order prohibited taking of deep sea precious corals throughout the area.

Unlike the Northwestern Hawaiian Islands Reserve, several other sanctuaries with known deep sea corals do not protect corals from fishing. A number of sanctuaries contain deep sea corals, but also allow bottom trawling. When scientists found a *L. pertusa* colony in the Olympic Coast Sanctuary, they also observed trawl tracks nearby (Hyland et al. 2005). The Monterey Bay, Cordell Bank and Gulf of the Farallones National Marine Sanctuaries all encompass deep sea coral habitats; portions of these sanctuaries fall within EFH designations. These EFH designations carry varying fishing restrictions, but this protection is implemented under the MSA rather than the Sanctuaries Act. As previously noted, sanctuaries have mostly left fishery regulation within their boundaries to NMFS and the regional fishery management councils. This is not required, but it is current practice. Two exceptions to this are no-fishing marine reserves within the Florida Keys National Marine Sanctuary and the Channel Islands National Marine Sanctuary. None of these reserves extend into significant deep sea coral habitats. For the most part, sanctuaries are in shallower coastal waters, and because they do not use their legal authority to regulate incompatible fishing practices, sanctuaries are not currently an effective mechanism for protecting deep sea corals.

Minerals Management Service

The Minerals Management Service (MMS), within the US Department of the Interior, manages the nation's energy and mineral resources in federal offshore waters of the US EEZ. Currently these activities primarily occur in 3 regions of the USA— the Gulf of Mexico, southern California, and Alaska— but may expand under current pressure to develop more oil and gas reserves and explore ways to harness energy from wind and waves. MMS is responsible for providing scientific and technical information to support decisions on the offshore energy and hard minerals programs; the extraction of which has the potential to damage the seafloor. Following the sale of lease blocks, MMS monitors resource development to determine the extent and duration of environmental effects and to identify potential mitigation measures. MMS is also required to collect and make available to the public any information needed to analyze, discuss, and guide future decisions on exploration, development, production, and proposed lease sales.

A number of MMS research programs are underway to study deep sea communities in the Gulf of Mexico, the primary region of oil and gas development in the USA. One mechanism used by MMS to mitigate impacts is to send a Notice to Lessees (NTL), that requires a minimum separation distance between the biological feature such as a deep sea coral reef and proposed seafloor disturbances. This has been used to protect deepwater chemosynthetic communities (NTL 88-11) in the Gulf of Mexico from oil explorations activities. MMS is also considering an NTL to protect *Lophelia* reefs in the Gulf (T. Ahlfeld, MMS, pers. comm.). Deep sea coral research programs are especially important because the expansion of oil and gas into deep water suggests the potential for greater conflicts with deep sea corals in the future (see Chapter 3 and Map 7).

Undetermined Habitat Value of Corals Limits Protection

Although EFH is currently the main mechanism used to provide protection for deep sea corals, it has significant limitations. In many coral areas, a dependence on coral habitats by commercial fish species or their prey has not yet been scientifically documented; therefore, these areas may not qualify as essential fish habitat. Bob Stone, Jon Heifetz and colleagues at NMFS have documented this dependence in the waters off Alaska (Heifetz 2002, Krieger and Wing 2002, Stone 2006). Grant Gilmore, Christopher Koenig, John Reed and others have shown similar associations between fish and *Oculina* coral off Florida (Gilmore and Jones 1992, Koenig et al. 2005, Reed et al. 2005a). However, other studies have been less conclusive.

Many fish and fisheries co-occur with deep sea coral habitats, but the precise nature of the association is unclear. The standard of scientific proof required by scientists and managers to designate deep sea coral habitats as EFH is unclear and appears to vary by region. In a few cases, fish appear to prefer three-dimensional structures, but do not differentiate between corals and other living or nonliving structures (Auster 2005, Tissot et al. 2006). Furthermore, fish of different sizes, ages and species behave differently, and may respond to an ROV by swimming away or hiding, making them difficult to observe. These factors complicate scientists' observations of how fishes use coral habitats and whether they depend on them. What scientists do know is that changes in habitat resulting from coral removal likely have influenced the survival and behavior of fishes (Sainsbury et al. 1997). Thus, current research on fish-habitat associations in these altered ecosystems may not accurately reflect the nature of these associations in an intact deep sea coral community.

In the Gulf of Maine, the density of fish does not seem to be affected by the presence of corals. Thus far, the only fish in the Gulf of Maine known to demonstrate a preference for coral areas over other structures for shelter and feeding grounds is the oreo, *Neocyttus helgae* (Auster 2005, Auster et al. 2005). However, since it is almost certain that fishing has altered deep sea corals in this region, the correlation between fish and corals may also have been changed (Watling and Auster 2005).

Within and surrounding the Christmas tree coral colonies off southern California (Figure 4.1), scientists observed large invertebrates and fishes, but the abundance of

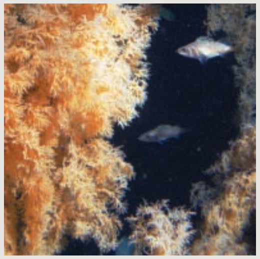
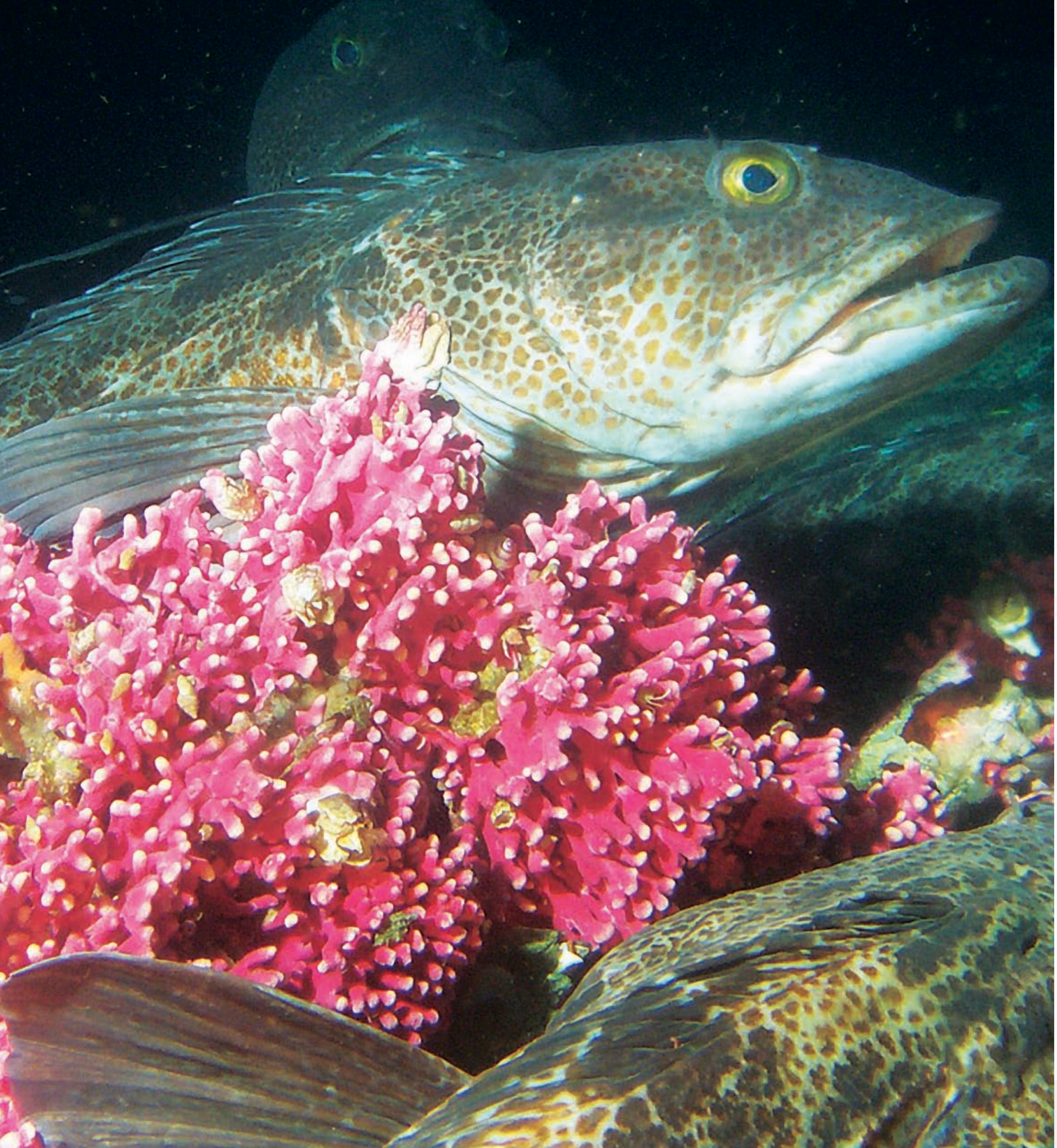


Fig. 4.1 Rockfish intermingled with Christmas tree corals near Santa Cruz Island, CA.
Photo credit: L. Snook

"A vast expanse of the planet's unexplored, and potentially most promising, ocean beyond the legal boundaries of nations is being exposed to the reckless plunder of marauding deep sea fishing trawlers."

Jean-Michel Cousteau, Founder and President, Ocean Futures Society

Opposite page: A white gorgonian coral tree (Paragorgia *sp.) with a large brisingid star on a seamount off New England. Photo credit: the Deep Atlantic Stepping Stones Science Party, IFE, URI-IAO, and NOAA*



these animals was low (Tissot et al. 2006). Only 8 of the 106 observed fish species showed higher concentrations inside the coral area as opposed to outside (Tissot et al. 2006). Possible explanations for the lack of a fish-coral association include the relatively small size (< 20 in.), low number or sparse density of observed corals, all factors which may alter the abundance of associated animals.

In and around black coral beds in the Main Hawaiian Islands (164–240 ft depths), researchers observed 40 fish taxa, suggesting that the tree-shaped corals (approximately 30 in high) may be an important fish habitat. One fish species (*Oxycirrhites typus*) was found exclusively in the coral beds, and 4 others used the corals as shelter to evade human divers (Boland and Parrish 2005). Some fish species use the corals more at night than during the day (Boland and Parrish 2005).

The necessity to prove functional relationships between fish and deep sea corals prior to EFH designation is squarely at odds with official assertions that require managers to manage in a precautionary manner and on an ecosystem basis. Until this issue is clarified, it will present a barrier to EFH designation and protective regulation in some council regions, and a hindrance to the conservation of deep sea corals under US jurisdiction.

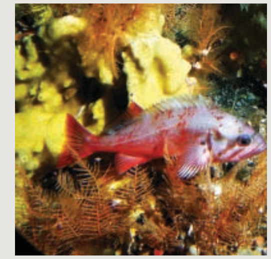
Current Protection for Deep Sea Coral is Inadequate

Deep sea coral protection must not be solely predicated on their value to commercial fisheries, but current ocean management, policies and practices limit comprehensive protection for deep sea coral habitats and ecosystems. Steps have been taken to protect deep sea corals under the existing authorities of the MSA, but most management actions are neither comprehensive nor focused on deep sea corals. In most cases, EFH designations and closures are gear or species specific. For example, although trawling and gillnetting for monkfish are prohibited in 2 submarine canyons in New England, other bottom-tending gears and bottom trawls not targeting monkfish can still be used to catch other species in those same canyons, potentially damaging deep sea corals. Seasonal rockfish closures along the US West Coast are only designed to reduce bycatch of certain depleted fishes, so while the closures temporarily restrict trawling, they cannot be expected to protect deep sea corals because trawling occurs during other seasons.

Bottom trawling must be properly managed in order to deal with the immediate and widespread threat to deep sea corals. However, even where areas are closed to bottom trawling with the clear purpose of protecting corals, the protection is limited if other fishing gears continue to be used. Many of the complete gear closures designated for deep sea corals are small, piecemeal, and opportunistic. Freezing the trawl footprint may close vast areas, but these areas may not contain the most important coral habitats. In addition, experience shows that enforcement of closures is generally inadequate. Expansion of vessel monitoring systems like those currently used in the North Pacific region would likely strengthen enforcement in other regions.

Summary

Current ocean management is insufficient to protect vulnerable and unique deep sea coral habitats. Fisheries management provides limited protection under existing laws, primarily through the designation of essential fish habitat (EFH) for federally managed species. Deep sea corals can be protected if the designation of EFH includes restrictions on fishing, but such provisions are not a requirement. The National Marine Sanctuary Program, the main program charged with protecting special ocean ecosystems, has the legal ability to regulate seafloor damaging fishing practices, but rarely uses it. Minerals Management Service can mitigate impacts of energy production by establishing buffer zones around deep sea coral communities, but has yet to do so.



Rockfish in deep sea sponge and coral community
Photo credit: R. Stone, NMFS

A large brisingid sea star from Manning Seamount
Photo credit: Jon Moore

Opposite page: Lingcod in hydrocoral bed in SE Alaska
Photo credit: V. O'Connell, ADFG

Until we make protecting ecosystems,

rather than exploiting resources,

the overarching goal of management,

we will continue to fall short of

protecting deep sea corals.

Status and Recommendations for Deep Sea Coral Protection

Deep sea corals are widespread in US waters, but threats to these organisms are also widespread, especially the dominant threat of bottom trawl fishing. Current management has limited ability to protect deep sea corals because it focuses on commercially important fish rather than on protecting habitats. Where deep sea corals are protected, regulations are seldom comprehensive, or if comprehensive, do not extend over large areas. Given that deep sea corals are extremely long-lived, are important habitats for other species, and are valuable in their own right, the protection of deep sea corals is an under-appreciated but key component of sustainable fisheries and healthy ecosystems.

In this chapter we summarize the status of deep sea corals, taking into account the spatial proximity of corals and threats and the quality of information available. We conclude with recommendations to improve deep sea coral management in the USA.

Current Status of Deep Sea Corals

Ideally, a status assessment would be based on a comprehensive examination of coral distributions, the health of coral populations, and the activities threatening them. The information that has been gathered in recent years by a variety of government, academic, and conservation organizations provides us with the first opportunity to examine the distribution of and threats to deep sea corals. However, significant data gaps still exist.

It is no coincidence that the deep sea coral area that is thought to be the most damaged and threatened, the *Oculina* Bank off Florida, is at relatively shallow depths— roughly 150 to 300 ft—and is relatively close to shore. Its proximity to humans makes it both vulnerable to fishing activities and relatively easy to study. It is one of the few places about which we have extensive information, yet the prognosis for corals in this area is relatively bleak. Within the Experimental *Oculina* Research Reserve over 90% has been destroyed by fishing (Box 5.1), despite awareness for over 20 years of this area and the impact of bottom trawl fishing.

In almost every other location in the USA, specific assessments are difficult to make. The detailed studies needed to document impacts are few and far between and are often focused on narrow transects (< 25 ft in width) across banks or ridges. Although the level of our understanding at present does not allow us to examine many areas or species in detail, general trends regarding the impact of human activities on deep sea corals can be identified.

It is clear from videotape footage and photographs that fishing gears that contact the seafloor are currently the greatest immediate threat to corals and that focus on limiting bottom trawling is the correct first step. Damage to corals from fishing has been shown to occur in multiple locations throughout the USA—from the Aleutian Islands to the banks of Florida. We know that bottom trawl-

Mushroom soft coral (*Anthomastus* sp.) on Davidson Seamount at 4,823 ft depth.
Photo credit: NOAA/MBARI

"Towing a heavy trawl net through a cold-water coral reef is a bit like driving a bulldozer through a nature reserve. The only practical way of protecting these reefs is therefore to find out where they are and then prevent boats from trawling over them. We know that most fishing boat skippers would rather steer clear of coral reefs, as the reefs can damage their gear, so producing accurate maps will actually help them to avoid these areas."

David Griffith, General Secretary of ICES (International Council for the Exploration of the Sea)

Opposite page: Live coral polyps in colonial coral.
Photo credit: Collection of Dr. James P. McVey, NOAA Sea Grant Program

ing and other fishing activities destroy corals and that these activities are widespread along the continental shelves of the USA. Only in the island regions of the Caribbean and Hawaii, therefore areas without continental shelves, is bottom trawling not an immediate threat to deep sea corals. Fishing activity and deep sea coral distributions substantially overlap in many regions, especially in the waters off Alaska, the US West Coast, and New England. There are also significant data gaps regarding the location and intensity of fishing. Without more detailed recording of fishing effort, bycatch, and landings, it is very difficult to determine the exact nature of the threat.

With the current trend towards fishing in deeper waters as coastal fisheries are depleted, there is a need to stem the expansion of fishing into the deep sea. The first step, to freeze the footprint of trawling, has been taken by the North Pacific and Pacific fishery management councils. The next step is to limit fishery impacts in other regions, such as the still intact *Lophelia* reefs of the southeastern USA. Steps are underway by the South Atlantic FMC to protect some of these known habitats.

As we gain greater knowledge of coral locations, protecting coral habitats within currently fished grounds will be a challenge for managers. Future protections for deep sea corals will need to be comprehensive, protecting them not only from bottom trawls, but from entanglement in bottom longlines or gillnets and from being crushed under crab or fish pots. Despite regulations that freeze the footprint of bottom trawling in the Pacific Ocean, the amount of known deep sea coral habitat that is entirely off limits to all types of bottom fishing is relatively small.

Finally, fishing is not the only human activity affecting the deep sea. Other activities undoubtedly have impacts; however, many of these are restricted to much smaller areas, are limited in scale, or, like climate change and increasing ocean acidification, are the result of widespread activities that are global in scale and hence exceedingly difficult to manage. One thing is clear—management can address the impacts of fishing, the most well recognized and certain threat to deep sea corals.

Recommendations to Improve Deep Sea Coral Conservation

It is clear that we should protect deep sea corals from further destruction. In this report we have identified key threats and obstacles affecting the conservation and management of deep sea corals, including: widespread bottom fishing in areas with deep sea corals; an institutionally constrained management focus on commercially important species (rather than habitat protection); a lack of data on deep sea coral distribution, ecology, and biology; gaps in monitoring and analysis of current and potential threats, especially fishing; insufficient use of closed area management (marine protected areas); and weak enforcement of regulations. To remedy

Box 5.1: Last Corals Standing — Protection of the *Oculina* Banks

The *Oculina varicosa* banks off central Florida are one of the relatively well-studied coral ecosystems in US waters. These reefs were first documented in 1963 based on commercial fishermen's reports, and scientists have surveyed the area multiple times since the 1970s. The area was listed as a candidate site by the National Marine Sanctuary Program in 1983, but never designated. However in the following year *Oculina* Bank Habitat Area of Particular Concern (HAPC) was created by the SAFMC, and closed to bottom trawl and dredge fishing gear. In 1994, the *Oculina* Bank HAPC was closed to all bottom fishing gear. In 2000, the HAPC boundaries were expanded to 397 mi^2 in order to protect a large portion of the remaining *Oculina* reefs. In 2003 the closure and its regulations were extended indefinitely.

Despite the attention of management for nearly a quarter century, protections have proven to be ineffective. A survey in 2001 found 90% of the areas designated in 1984 contained only coral rubble, and only 0.3 mi^2 (or 9.5 baseball fields) of intact deep sea coral reefs remain. Nearly all the corals had been demolished by trawl gears. Furthermore, *Oculina* reefs outside the HAPC are being demolished; a mound off Cape Canaveral that was 100% covered by live *O. varicosa* colonies in 1976 retained only a few scattered colonies in 2001, a year after it became part of the *Oculina* HAPC.

Bottom trawling for rock shrimp is the primary threat to the *Oculina* reefs, and illegal trawling has occurred in the *Oculina* HAPC as recently as 2004. Abandoned longlines and trawl nets that entangle corals, trawl tracks on the seafloor, and sightings of trawlers in the protected area are evidence that fishing activities are destroying the fragile *Oculina* reefs. Obviously enforcement has been poor.

Through the last 3 decades of research on the *Oculina* reefs, scientists have demonstrated that the reefs are breeding and feeding grounds for groupers and snappers; measured the reefs' slow growth rate (0.6 in per year); discovered reefs that are 1,500 years old; and identified many locations of *Oculina* occurrences. Our understanding of *O. varicosa* far exceeds that of other deep sea coral species. However, none of this has prevented the devastation of the *Oculina* reefs. Immediate action to make deep sea coral protection a national priority, coupled with strict enforcement, heavy penalties, and further research, monitoring, outreach and education, is the remaining corals' only hope for survival.

Sources: Reed et al. 2005a, Koenig et al. 2005

Table 5.1: Current deep sea coral management actions and their limitations.

Current Management Action	Limitations	Remedy
Designating selected coral areas as EFH for commercial fish species (e.g., Oceanographer Canyon in the New England region)	EFH designation is subject to interpretation by councils. Definitions vary by region.	A national mandate to define and protect deep sea corals comprehensively through ecosystem-based management (EBM).
	EFH is not required to have conservation regulations.	A national mandate to define and protect deep sea corals comprehensively through EBM.
	Where fish dependence on corals has not been established, deep sea corals are not protected.	Research and mapping, precautionary approach to management that will protect all deep sea coral concentrations.
Freezing the footprint of bottom trawling (e.g., around the Aleutian Islands in the North Pacific region)	Areas closed to bottom trawling may encompass fewer deep sea corals or corals that are not currently threatened.	Increase research efforts to map known coral concentrations in areas open to trawling.
Setting up protected areas specifically for deep sea corals (e.g., *Oculina* Bank in the South Atlantic region)	Enforcement and monitoring of closure in offshore areas is challenging.	Increase the use of vessel monitoring systems (VMS) and onboard observers.
Prohibiting bottom fishing to restore depleted fish populations with incidental effect of protecting deep sea corals (e.g., Rockfish Conservation Area in the Pacific region)	Could push fishing effort from low coral abundance areas to high coral abundance areas.	A national mandate to define and protect deep sea corals comprehensively through EBM.
National Marine Sanctuary Program (e.g., Olympic Coast National Marine Sanctuary in the Pacific region)	The Sanctuaries Act allows multiple uses to occur in a sanctuary, many of which are incompatible with coral conservation.	A national mandate to define and protect deep sea corals comprehensively through EBM. Better use of existing authority to regulate bottom contact gear damage to corals.

"We are protecting less than one percent of our oceans. If we are to protect this priceless natural heritage for future generations, we must learn to value marine life less as commodities and more as part of the natural world on which we too depend."

Dr Sylvia Earle,
Executive Director of Conservation International's Global Marine Division and Explorer-in-Residence at the National Geographic Society

*Opposite page: Basket star (*Gorgonocephalus eucnemis*) perched atop a yellow sponge (*Staurocalyptus *sp.) on the Davidson Seamount (4,469 ft depth).*
Photo credit: NOAA/MBARI

Box 5.2: Bottom Trawl and Deep Sea Coral Habitat Act of 2005

As proposed, the Bottom Trawl and Deep Sea Coral Habitat Act would provide significant protection for fragile and ecologically significant ocean habitats by changing the way deep sea coral habitats are managed. Specifically, the Act would allow bottom trawls to be used in almost all areas where the gear has been used in the past 7 years for which records are available, while establishing a national mandate for deep sea coral protection. The Act contains the following provisions:

- Temporarily bans the use of bottom trawl gear in unstudied areas (any area in which records indicate that mobile bottom tending fishing gears have not been used) until research determines whether deep sea coral ecosystems are present. If no deep sea coral ecosystems are found in an area, that area could be opened for the use of bottom trawls and designated a Bottom Trawl Zone.

- Permanently bans bottom trawling in Coral Habitat Conservation Zones where deep sea coral ecosystems are known to exist.

- Requires monitoring of coral bycatch. High bycatch levels are an indicator of the presence of deep sea coral ecosystems. Areas that produce high bycatch levels would be studied for potential designation as Coral Habitat Conservation Zones under the authority of the Secretary of Commerce.

- Requires all bottom trawl vessels fishing in waters deeper than 50 m (~165 ft) to carry a vessel monitoring system (VMS) device.

- Provides for penalties and enforcement of the Act.

- Authorizes $15,000,000 a year to carry out the provisions of the Act.

these problems we provide the following recommendations for deep sea coral protection:

Recommendation 1: Use and enforce existing laws to protect deep sea corals.

Recommendation 2: Establish a national mandate to protect deep sea corals.

Recommendation 3: Expand scientific research (basic and applied) of deep sea corals.

Recommendation 4: Implement ecosystem-based management.

RECOMMENDATION 1: Use and Enforce Existing Laws

Current laws and federal fishing regulations allow fishery management councils to enact spatial closures (marine protected areas) to protect deep sea corals from trawling and other potentially damaging fishing gears, including longlines, dredges, fish traps, crab pots, and bottom gillnets. Essential Fish Habitat and Habitat Areas of Particular Concern designations must be accompanied by restrictions on all fishing gears that affect seafloor habitats and deep sea corals. Closed areas should also be surrounded by a buffer zone that prevents inadvertent damage from fishing activity, and fishing permits must require vessel monitoring systems (VMS). In addition, deep sea coral closures should be accompanied by research and monitoring plans as well as education and outreach activities.

As noted for *Oculina* Bank HAPC (Box 5.1), enforcement of existing regulations remains a challenge. Authorities should examine additional means of enforcement, including event data recorders, vessel monitoring, and at-sea surveillance. We recommend that all fishery management councils adopt a precautionary approach to management that will restrict expansion of fisheries until they demonstrate that the gear used is compatible with sustainable fishing, habitat protection, and maintenance of healthy ecosystems.

The National Marine Sanctuaries Program should re-examine and use its mandate to manage all habitats within sanctuary boundaries, and regulate uses incompatible with resource protection.

The Minerals Management Service should act on existing information on the locations of deep sea coral and provide suitably sized buffers between deep sea coral areas and exploration, drilling, and other extraction and energy production activities.

RECOMMENDATION 2:

Establish a National Mandate to Protect Deep Sea Corals

Limitations to current laws, including the Magnuson-Stevens Act (MSA) and the National Marine Sanctuaries Act, prevent comprehensive protection of deep sea coral ecosystems. This suggests that a new mandate from Congress is needed. At this time the MSA is undergoing reauthorization by Congress, and the Bottom Trawl and Deep Sea Coral Habitat Act of 2005 (introduced in the House and Senate as H.R. 3778 and S. 1635) could be used as an amendment to the MSA or as new legislation. Modeled on the actions taken in the Pacific and North Pacific FMC regions, the bill would freeze the footprint of bottom trawlers and protect deep sea corals that have not yet been demolished, while allowing bottom trawlers to continue to fish in areas where they have historically fished. The bill would also provide for the implementation of vessel monitoring and for increased coral research efforts in the deep sea. The provisions of the bill are summarized in Box 5.2.

RECOMMENDATION 3:

Expand Science and Research

Continued research is critical to furthering our understanding of deep sea corals and improving their management. The quality of information on the distribution of deep sea corals varies from one region to another because of different research methods and priorities. NMFS and its regional science centers have undertaken excellent small-scale studies of coral and fish habitats. The National Undersea Research Centers and other academic centers have also provided valuable research. NOAA's Office of Ocean Exploration has sponsored a series of research cruises in recent years to better understand deep sea coral distribution and ecology. These cruises explored seamounts off California, New England and the Gulf of Alaska, as well as the *Lophelia* and *Oculina* reefs of the southeastern USA, the coral gardens of the Aleutian Islands, and several other areas. On these explorations, manned submersibles and ROVs captured images of deep sea corals and collected samples for further analyses. This provided a detailed look at selected deep sea coral communities and documented the locations of corals. However, each study covered only a small area or a few narrow transects.

*Red vermillion crab (*Paralomis verrilli*) dangling off a yellow sponge (*Staurocalyptus *sp.); amidst a white ruffle sponge (*Farrea *sp.); white branched sponges (*Asbestopluma *sp.); shrimp; brittle stars; and an isopod on the Davidson Seamount (4,462 ft depth). Photo credit: NOAA/MBARI*

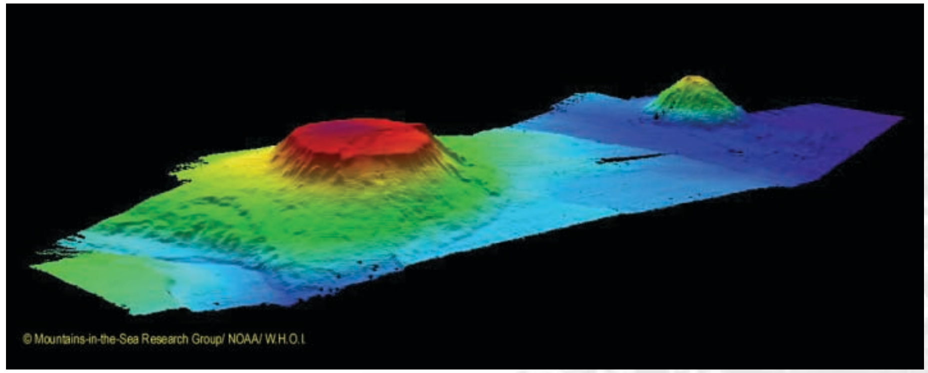


Fig. 5.1: Map of Bear Seamount (foreground) and Physalia Seamount (background), in the New England seamount chain, produced with multi-beam sonar shows detailed bathymetry
Image credit: Mountains in the Sea research group/NOAA/WHOI

Greater use of multibeam sonar mapping of the seafloor will facilitate scientific exploration (Figure 5.1). Unlike trawl surveys, seafloor mapping will provide much greater spatial resolution of potential coral locations. When paired with ground-truthing efforts using ROVs or manned submersibles to confirm the presence of deep sea corals, this technique will offer a much more precise and accurate understanding of coral distribution (Schroeder et al. 2005).

Future research should continue to identify coral communities for protection. A comprehensive research program for deep sea corals needs to:

1. Fund further exploration work to identify coral concentrations;

2. Develop high-resolution multi-beam mapping of continental shelves and slopes with ground truthing from ROVs or manned submersibles;

3. Develop and fund new tools such as autonomous underwater vehicles (AUVs) for sampling and mapping environmental factors;

4. Develop models to predict deep sea coral distribution based on hydrography and geology;

5. Produce higher resolution, spatially explicit maps of fishing effort and landings to facilitate the assessment of the threat of fishing to deep sea corals;

6. Research impacts of all fishing gears on seafloor habitats, as well as the recovery of these areas from fishing;

7. Fund research in basic taxonomy of deep sea corals;

8. Substantially improve deep sea coral identification training for fishery observers;

9. Use fishermen's knowledge to augment data on deep sea coral occurrences.

RECOMMENDATION 4:

Implement Ecosystem-Based Management

The challenges of deep sea coral conservation exemplify the multiple conflicting uses of marine resources, from fishing and petroleum activities to harbor dredging and anchoring. Management cannot succeed when multiple agencies operate under different, often conflicting mandates that only address individual pieces of a larger ecosystem. Habitat conservation will not occur without a coherent approach to management that focuses on maintaining the structure and function of the ecosystem.

Implementation of ecosystem-based management (EBM) for an entire region will markedly improve the conservation and management of deep sea corals for 3 reasons. First, EBM addresses more than commercially valuable species and seeks to maintain habitats and ecosystem function (Pikitch et al. 2004, Murawski 2005). In EBM, deep sea corals do not have to be proven essential for commercial fishes before receiving protection. The habitat complexity that deep sea corals contribute to the seafloor is enjoyed by commercial and noncommercial fishes alike, and EBM lends itself to protecting all parts of the ecosystem regardless of their commercial value. EBM departs from the single-species approach to fisheries management and limits collateral damage of fishing on the ecosystem. Deep sea corals will thus gain comprehensive protection from fishing as opposed to the haphazard, piecemeal case-by-case and gear-by-gear management actions that have taken place so far. EBM would also benefit other cnidarians and sponges, which play important roles in structuring the seafloor.

Second, EBM integrates the management not only of fishing activities but also of other human impacts on the ecosystem (Rosenberg and McLeod 2005). It provides a framework for assessing the consequences for deep sea corals of energy development, waste dumping, cable laying, climate change, and other activities. More important, EBM allows us to evaluate and manage the synergistic impacts of all these threats combined.

Third, EBM bases adaptive management on the precautionary principle. EBM places the burden of proof on those whose activities affect the ecosystem (Murawski 2005, Pikitch et al. 2004). Under EBM, the fishing industry would be required to prove that fishing does not result in detrimental effects on the habitat of a particular area before fishing is allowed there. As scientific understanding progresses and ecosystem components and their functions are better understood, management can adapt and regulate activities that are either compatible or incompatible with specific ecosystem properties. Given that new locations and species of deep sea coral are discovered every year and deep sea coral research is expanding at a fast pace, adaptive management is a suitable approach for integrating new research findings into the crafting of protection measures.

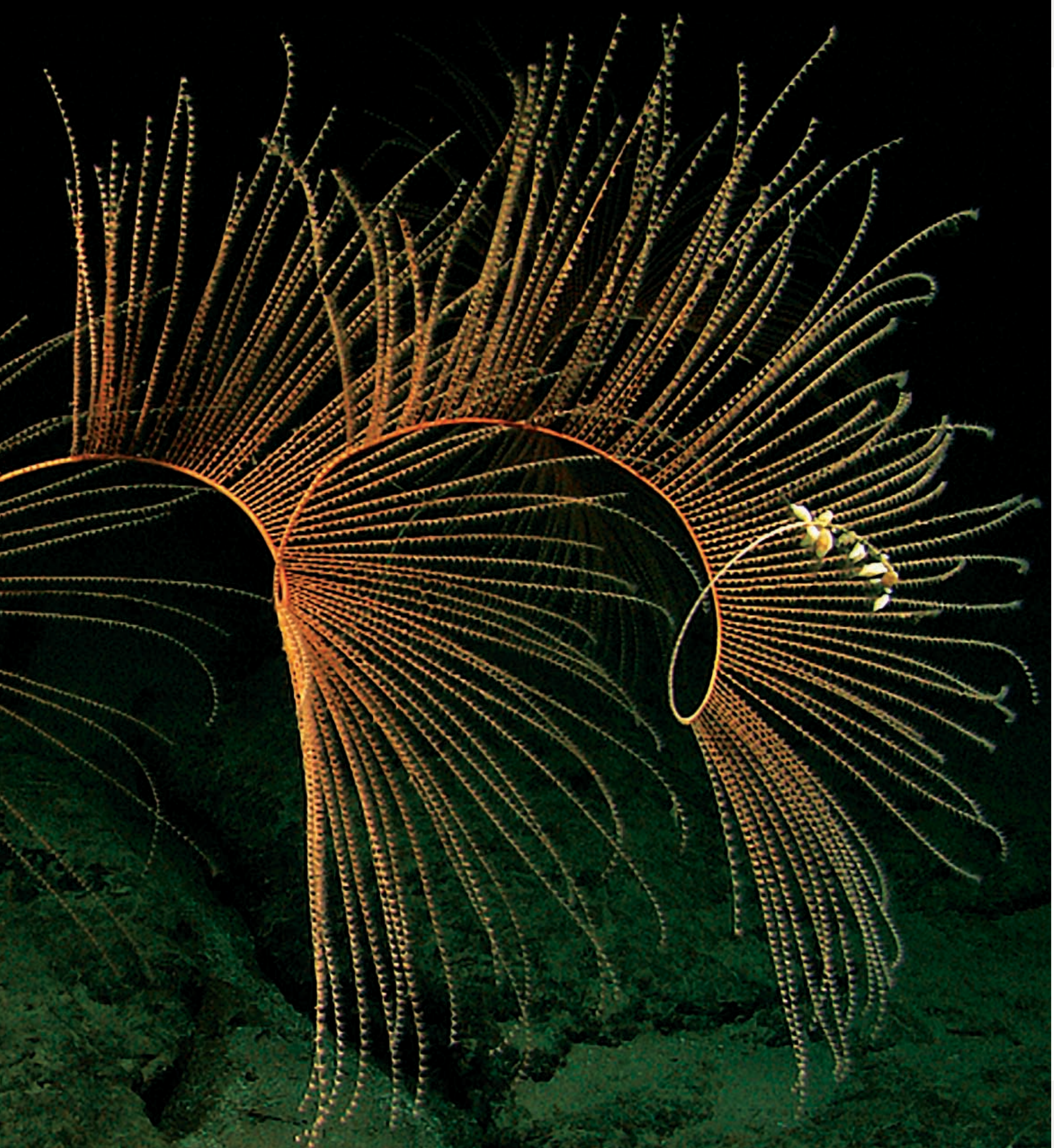
In recent years, managers of commercial fisheries in the USA have begun to recognize the interconnectedness of exploited species and their supporting ecosystems. NMFS appears to be committed to viewing fishery management as more than the sum of multiple fishery stock assessments (Murawski 2005). This is very good news to those concerned with biodiversity conservation, but current laws continue to do a

The manned submersible Johnson-Sea-Link contributed greatly to our understanding of the *Oculina* Banks and *Lophelia* deep sea coral reefs.
Photo credit: HBOI

"The deep ocean, ranging in depths up to 10,000 meters, is an amazing cradle for an estimated 500,000 to 10 million species, many of them still undiscovered."

Jean-Michel Cousteau, Founder and President, Ocean Futures Society

Opposite page: Big white coral (Family Primnoidae)
Photo credit: NOAA/MBARI



disservice to marine organisms that are not "proven" contributors to commercial fisheries.

Comprehensive ocean zoning offers a means of implementing EBM that will help manage multiple uses (Norse 2003, 2005, Pew Oceans Commission 2003, Pikitch et al. 2004). Ocean zoning provides for multiple uses within a defined area, combining compatible activities and avoiding overlap of incompatible ones. In order to protect deep sea corals, zoning must start with the clear conservation goal of allowing activities compatible with the maintenance of ecosystem structure and function, but severely restricting activities that harm the seafloor. Of course, for zoning to prove effective it will need to address all human

*Left: An eight foot tall spiraling colony of gorgonian coral (*Iridogorgia *sp). Scientists using a remotely operated vehicle (ROV) to study seamounts off New England in 2005 captured this image with a high-definition video camera. Scientists visited 10 seamounts in the northwest Atlantic with the ROV; mapped the seafloor with multibeam sonar; collected over 337 samples of corals, sponges and associated fauna; identified and documented the habitat and foraging behavior of dozens of fish species; and took thousands of digital still images and frame captures of seamount landscapes.*
Photo credit: Deep Atlantic Stepping Stones Science Party, IFE, URI-IAO, and NOAA

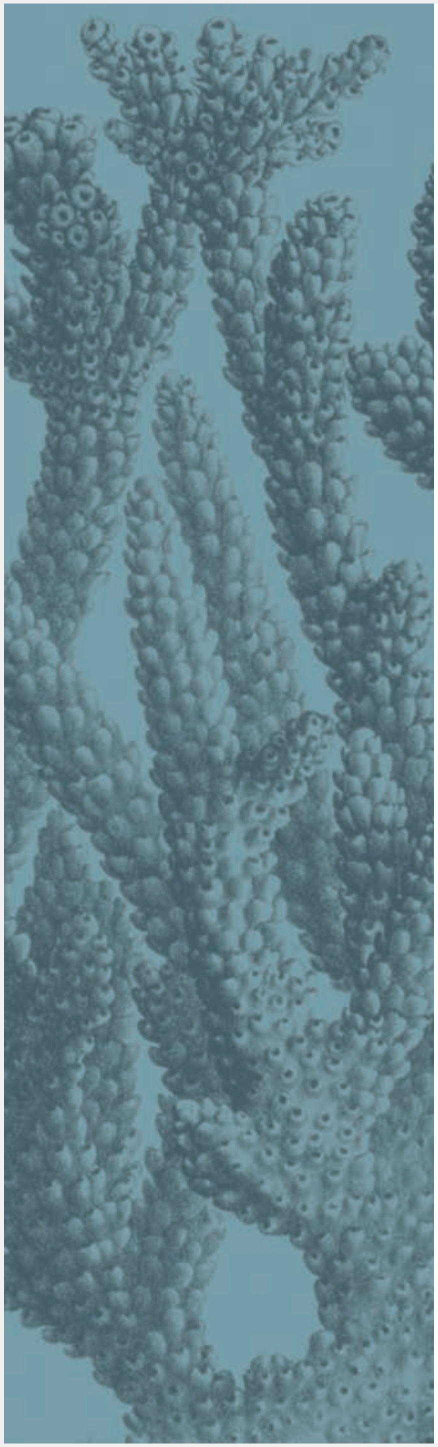
activities. This will require an extensive commitment to research and mapping as well as discussion and negotiations about the best uses of particular marine habitats. One opportunity on the horizon is the idea of designating allowable fishing zones. This would be in line with a precautionary approach to management, whereby selected areas would be open to fishing based on the compatibility of gears with particular habitat types. Because the future will undoubtedly see greater human activity at sea, it is time to bring ecosystem and zoning concepts into ocean management.

Conclusions

Deep sea corals are threatened by a number of human activities, but the largest and most immediate threat comes from bottom trawl fishing. This conclusion echoes recent findings by the National Research Council in 2002, the Pew Oceans Commission in 2003, and the US Commission on Ocean Policy in 2004 that bottom fishing, especially bottom trawling, is a major threat to deep sea corals. These bodies recommend stricter protection of vulnerable coral habitats. Similarly, the President's 2004 Ocean Action Plan emphasized deep sea coral conservation and called for further identification and protection of deep sea coral areas. Despite these encouraging signs, progress towards increased deep sea coral protection has been slow. Freezing the footprint of bottom trawling under fishery management council regulations limits the expansion of fishing fleets, but does not protect known coral locations in currently fished areas. The deep sea coral areas that have been comprehensively protected are small in relation to the overall need.

The recommendations of this report seek primarily to address the most significant threat to deep sea corals—bottom trawling—and to address additional impacts in a stepwise manner. First, fishery management councils and national marine sanctuaries must use existing tools to protect deep sea corals and curtail any further expansion of bottom trawling unless it can be shown that trawling will not damage seafloor habitats. Second, a national mandate to protect deep sea corals is necessary. Third, government-funded research should devote resources to achieving a better scientific understanding of where deep sea coral communities are found and of their ecological roles. Last, managers must develop a comprehensive framework to manage all human activities based on their compatibility with different ocean habitats (i.e., ecosystem-based management and ocean zoning). Until we make protecting ecosystems, rather than exploiting resources, the overarching goal of management, we will continue to fall short of protecting deep sea corals, sustaining healthy fisheries, and maintaining the oceans' productivity and biological diversity.

Right: Iridigorgia *sp. collected at Kelvin Seamount. Photo courtesy of M. Grady.*



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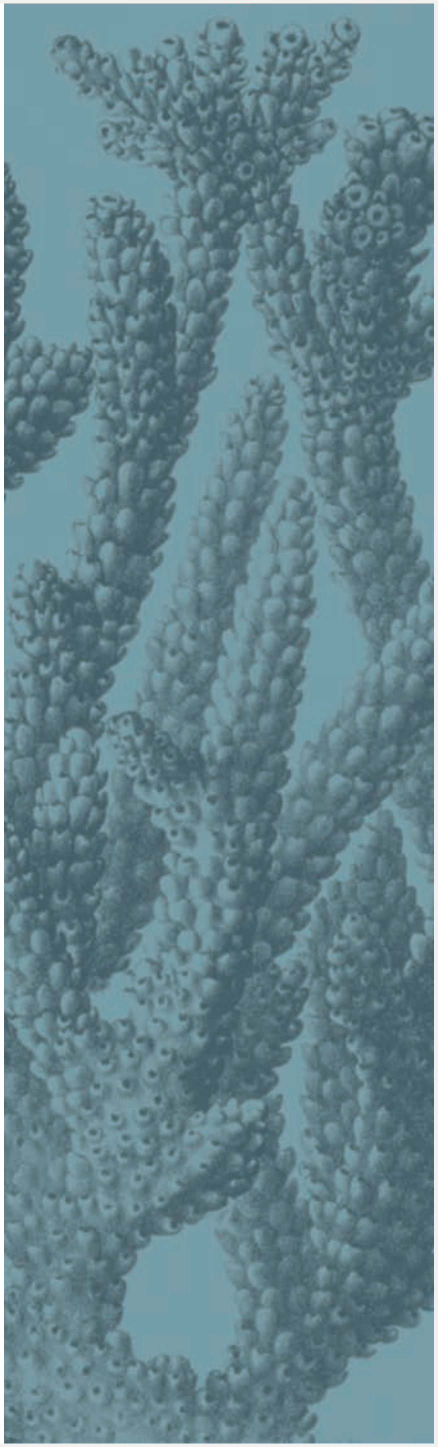

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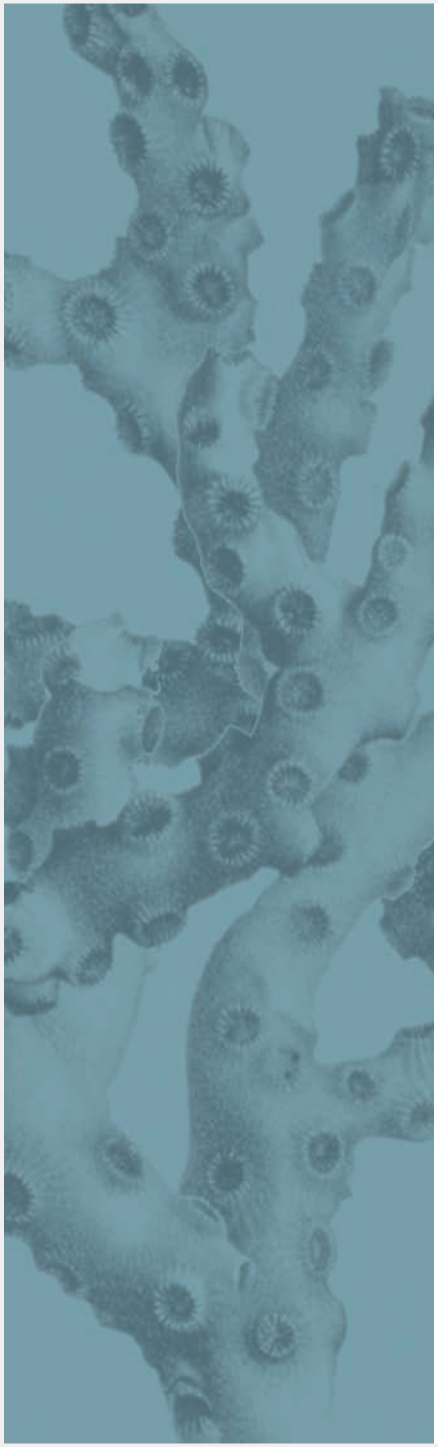

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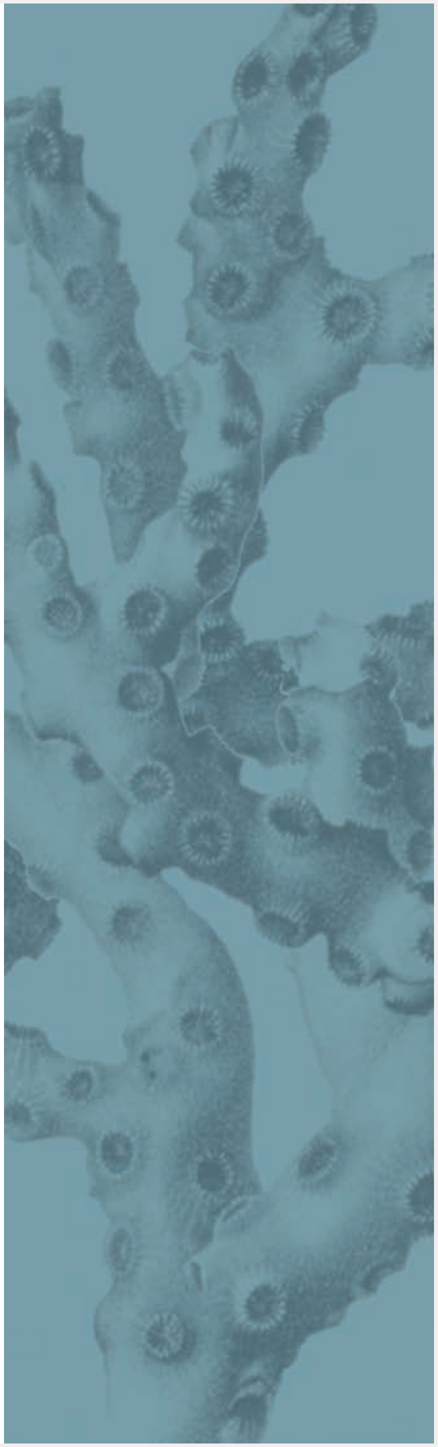

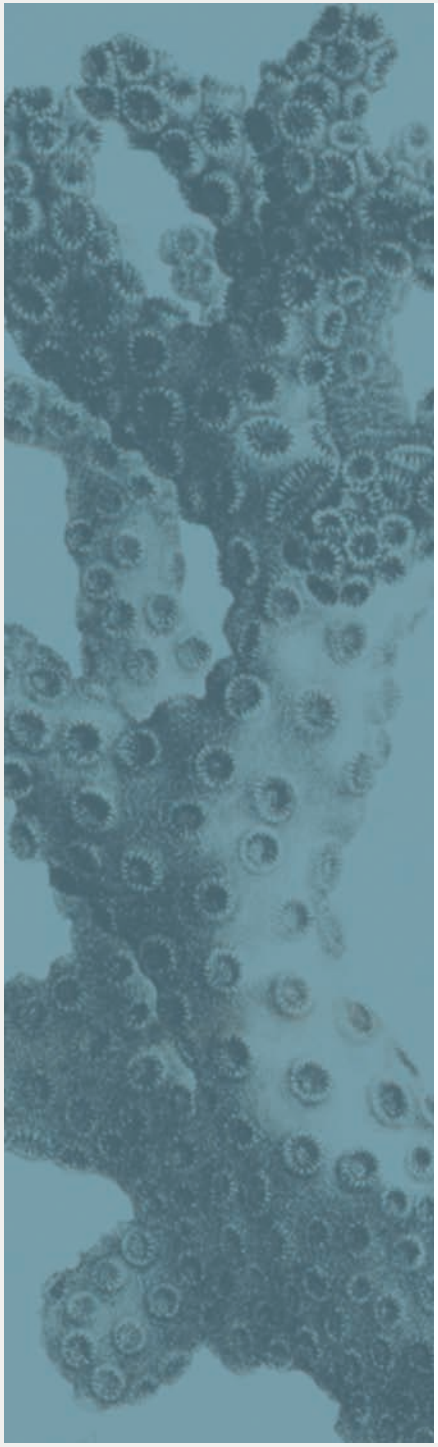

Appendix: Data Sources for Maps

Bathymetry:

ETOPO-2 — seafloor data between latitudes 64° North and 72° South. These data were derived from satellite altimetry observations and shipboard echo-sounding measurements. For more information see Smith, W.H.F. and D.T. Sandwell, 1997. Global sea floor topography from satellite altimetry and ship depth soundings. Science **277** (5334): 1956–1962.

Deep Sea Coral Records:

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Schroeder et al. 2005
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Watling et al. 2003
Stephen Cairns, Smithsonian Institution
Peter Etnoyer, Aquanautix Consulting
André Freiwald, University of Erlangen
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John Reed, Harbor Branch Oceanographic Institution
John Warrenchuk, Oceana
California Academy of Sciences
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Monterey Bay Aquarium Research Institute
Monterey Bay National Marine Sanctuary
Smithsonian Institution
Scripps Institution of Oceanography

Fishing Catch and Effort data:

Tom Hourigan, NMFS
John Olson, NMFS
David Stevenson, NMFS

EEZ Boundaries:

General Dynamics Global Maritime Boundaries Database

Gulf of Mexico Oil Platform and Pipelines:

US Minerals Management Service

Essential Fish Habitat Boundaries:

North Pacific Fishery Management Council
Pacific Fishery Management Council
South Atlantic Fishery Management Council

Data sets used with permission.
Available from MCBI by request.

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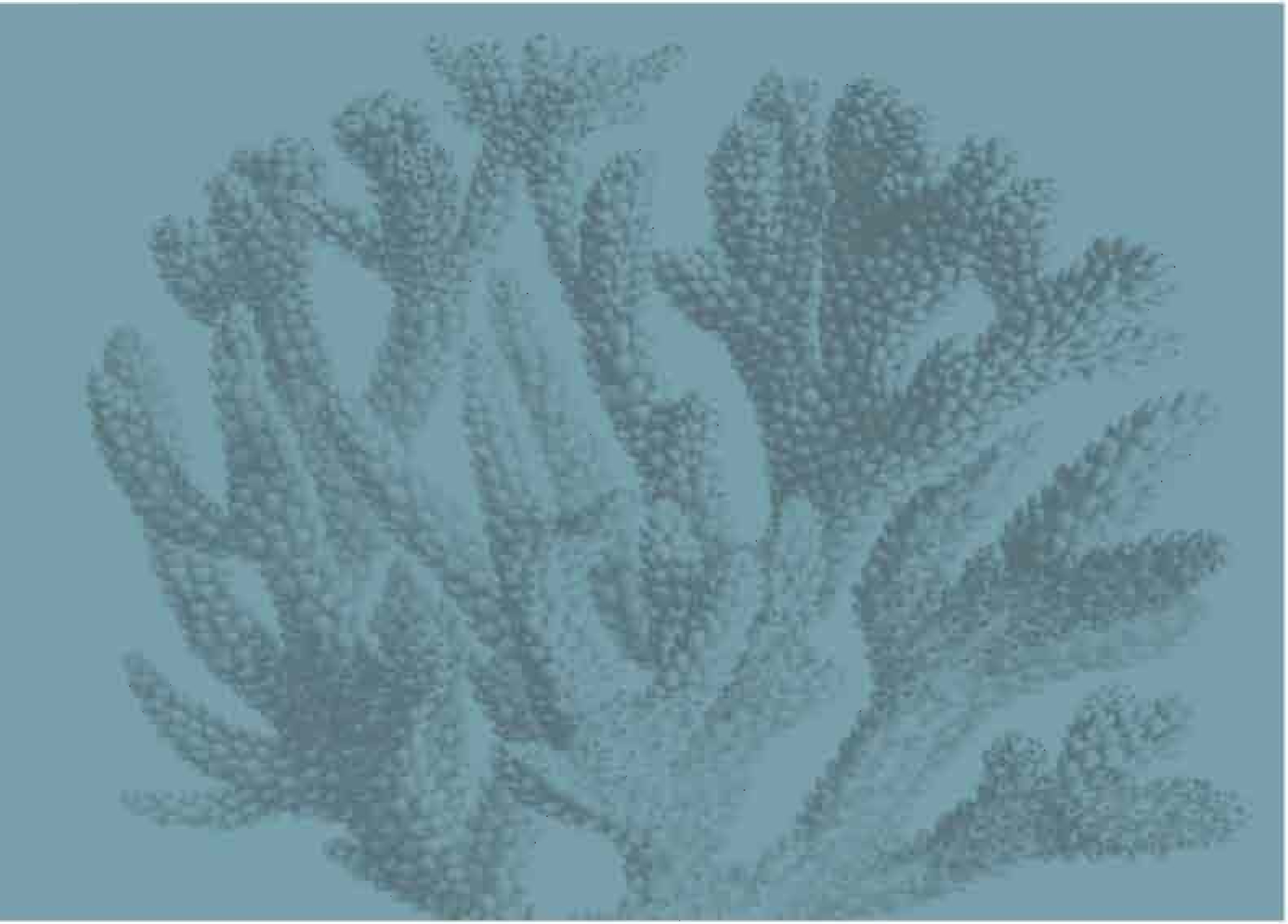

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