DEEP SEA LIFE:

ON THE EDGE OF THE ABYSS

OCEANA

It is the special burden of marine conservationists that people can not easily see what happens underwater. The sea remains inscrutable, mysterious to most of us. On land we see the effects of our activities and we are constantly reminded of the need for action, but we see only the surface of the sea.
Rodney Salm and John Clark (IUCN)

The oceans are the planet's last great living wilderness, man's only remaining frontier on earth, and perhaps his last chance to prove himself a rational species.
John L. Culliney, Wilderness Conservation,
September – October 1990

Nature shows us only surfaces, but she is a million fathoms deep.
Ralph Waldo Emerson (1803-1882)

It's life, Jim, but not as we know it.
Bones McCoy, U.S.S. Enterprise

DEEP OCEANS: THE FINAL FRONTIER

The deep sea is the last great frontier on Earth. For hundreds of years people have pondered, debated and explored the vast depths of the oceans, yet our knowledge of them barely skims the surface. Remarkably, though it is the largest ecosystem on Earth,[1] we have better maps of Mars than we do of our own planet's seafloor.[2] What little light we have shone on the deep has illuminated life that was old when Rome fell and ancient when Christopher Columbus rediscovered the Americas.[3]

We know that the deep sea is an environment of extremes – high pressures, freezing and superheated water, and sparse food resources. Sunlight fades into almost complete darkness only 600 meters from the surface.[1] The consequent lack of plants fueled debate among scientists as to whether life existed at all in the deep sea[4] until the pioneering voyage of the HMS Challenger (1872-76) provided persuasive evidence to the contrary. It was not until the 1960s that scientists began to realize that the ocean depths are home to a variety of life approaching that of tropical rainforests.[5] Some researchers now suggest that the deep sea is the place on Earth where life began.

> The deep sea is no longer unspoiled wilderness. The damaging effects of human activities from bottom trawling to pollution can now be seen in every ocean.

With improved technologies, scientists are better able to study the deep seas, and they are making dramatic new discoveries almost routinely. We have learned that deep sea corals attain ages best measured in centuries and millennia, and that some of the fish that swim among them are far older than the oldest human. We have discovered unknown life forms and creatures thought extinct since the time of the dinosaurs, and entire ecosystems that get their energy from the center of the Earth rather than the Sun. And yet, we've only explored a tiny fraction of the deep oceans.

The Gold Rush in the Blue Ocean

The deep ocean is no longer unspoiled wilderness. Improved technologies have allowed the expansion of some of our activities into the deep sea. By far the largest current threat is from destructive commercial fishing practices. Likened more to clear-cutting than fishing, destructive trawling in particular has caused considerable damage to deep sea communities on the continental slope and on undersea islands called seamounts. Trawling can destroy centuries of coral and sponge growth in a single pass, and pulls to the surface myriad unwanted animals that are simply thrown back dead or dying. Unfortunately, few laws and regulations protect deep sea communities from bottom trawling. Virtually no protections at all exist on the high seas – two thirds of the entire ocean – because they fall outside the jurisdiction of any national government.

Fishing is not the only threat to the deep sea. The effects of contamination from land-based toxic pollutants such as mercury, PCBs, and DDT, and the consequences of many decades of dumping munitions, and chemical and nuclear wastes into the deep sea are unknown and little studied. Oil and gas exploration and drilling has already expanded into deeper areas and seabed mining for valuable minerals, although not yet economically feasible, may follow.

What Needs to be Done?

Our exploitation of the deep sea will only expand. Some of our activities are already causing serious damage to life deep beneath the waves, and without precautionary measures others will likely do so in the future. This report contains specific recommendations to ensure that our activities are managed so that the remarkable life deep in the ocean continues to thrive. The last great living wilderness on Earth is also perhaps our last chance to prove that we can act as part of the flourishing web of life rather than its antagonist.

DISCOVERING THE DEEP SEA

Not so long ago, scientists had only the vaguest notion of what could be found on the seafloor. Most assumed it was a vast plain, empty and still – almost devoid of life, without even ocean currents. Over the last few decades, scientists' understanding of the deep sea and its abounding life has become much clearer. As Rachel Carson wrote in her now-classic *The Sea Around Us*, "instruments and equipment, most of which had been born of urgent necessity, gave oceanographers the means of tracing the contours of the ocean bottom, of studying the movements of deep waters, and even of sampling the seafloor itself."[6] In the 1960s, oceanographers using early submersibles were astonished to learn that familiar landscape features, such as great plains, deep canyons, mountain ridges and seamounts, shape the deep ocean floor in the same way they do on land.

The deep sea holds some of the most remarkable marine life we know. This overview is meant to provide context for the following sections, which describe the exquisite adaptations of deep sea fish and marine communities living on and around seamounts, deep sea corals, hydrothermal vents, cold seeps, and even whale skeletons.

Deep

The continents do not simply stop at the coasts. From the beach, continents slope gently toward the deep sea, forming the continental shelf, which may extend for only a few to several hundred miles from shore. At roughly 200 meters deep, the seafloor drops off sharply, and is then considered the continental slope. Scientists often refer to the break point between the continental shelf and slope as the beginning of the deep sea, as it is the transition zone between the shelf fauna and those from deeper waters.[7]

Sunlight fades fast in the sea, with less than one percent reaching depths of more than 200 meters . Thus all marine plant growth in the oceans occurs on or over continental shelves or seamounts (the deepest plant discovered to date was on the top of a seamount 200 meters beneath the waves)[8] or in the surface waters of the open ocean. Virtually all life in the ocean is supported by these surface waters, as plants and the animals that eat them grow and die, forming a seasonal 'rain' of food to the deep sea. Light and the availability of food heavily influence the distribution of life within the oceans,[9] and many of the special adaptations seen in deep sea animals are likely because of these two factors. The twilight zone between 200 and 1,000 meters, beneath which sunlight has all but gone, is home to many mobile animals such as fish, squid and crustaceans that make nightly forays into food-laden surface waters.

Deeper

Where the continental slope ends in the ocean depths, so does the continent itself. This demarcation point is often obscured by the continental rise, a build-up of sand, mud and organic matter that has been washed off the continental shelf by currents. The rise begins at about 3,000 meters and ends at 4,000 meters, and can stretch for hundreds of miles between those depths.

The continental slope is also broken up by dramatic canyons, some of which are larger and deeper than the North American Grand Canyon. Animals such as deep sea corals live on the sides of these canyons and filter food from the faster currents.[5] From 1,000 meters down to 4,000 meters, just slightly deeper than the average depth of the oceans, is the midnight zone. The only real source of light at these depths is from deep sea creatures that produce their own light to attract prey or mates. These waters are home to mainly non-migrating crustaceans and fish.

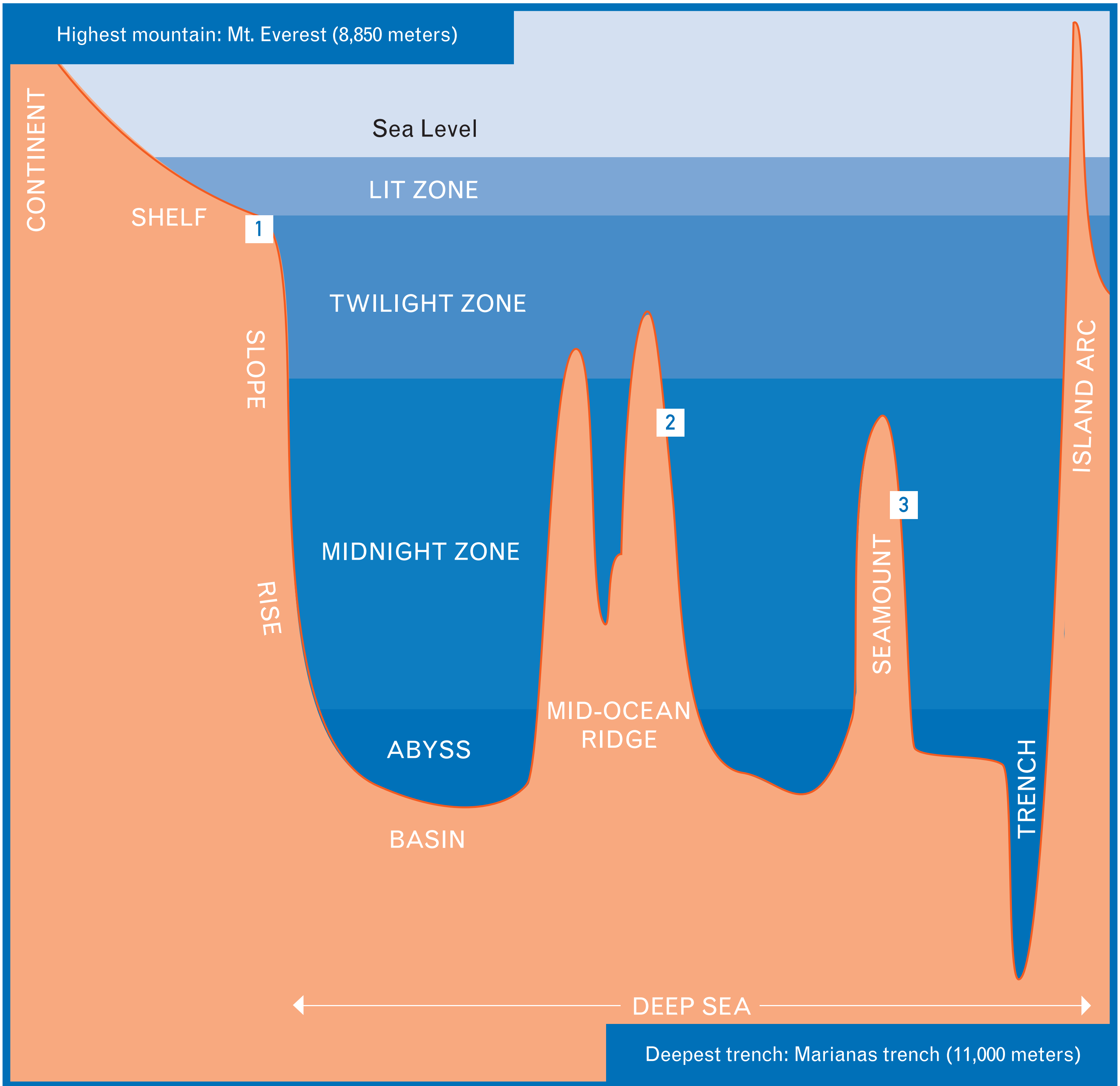
Deepest

From the base of the continental rise the deep sea basin or abyss seems to stretch without end, covering about fifty percent of the ocean. Breaking the monotony of the muddy deep sea floor known as the abyssal plain are long mountain ranges called ocean ridges, isolated mountains known as seamounts, and oceanic trenches, the deepest places known.

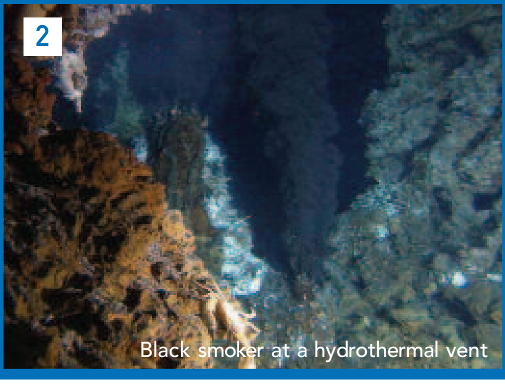
The mid-oceanic ridges are essentially one inconceivably long mountain range that winds its way through all the oceans, seemingly holding the continents together like the stitches on a patchwork quilt. They form the largest volcanic feature on Earth, where new ocean floor is continuously created, renewing the surface of the planet. Incredibly, bountiful life exists even in this deepest zone, where underwater geysers called hydrothermal vents are home to some of the strangest, most exquisitely adapted life we know. Fantastic and remarkable life also exists on seamounts, undersea islands that accelerate the slow deep ocean currents and provide oases of refuge and biological diversity from the surrounding expanse. In places, even the abyss suddenly drops off from 6,000 meters to more than 9,000 meters. The Marianas Trench in the west Pacific, the deepest place on Earth, is more than 11,000 meters below sea level, 25 percent deeper than Mount Everest is high. One of the deepest living animals ever discovered, an unidentified sea cucumber, was taken from another west Pacific trench, the Philippine Trench, at more than 10,400 meters deep.

Distinct depth zones within the open water support marine life according to varying sunlight and available food. Underwater mountains, trenches, and rolling plains define the seafloor and support vibrant communities of marine life.

LANDSCAPES OF THE DEEP



Oculina coral

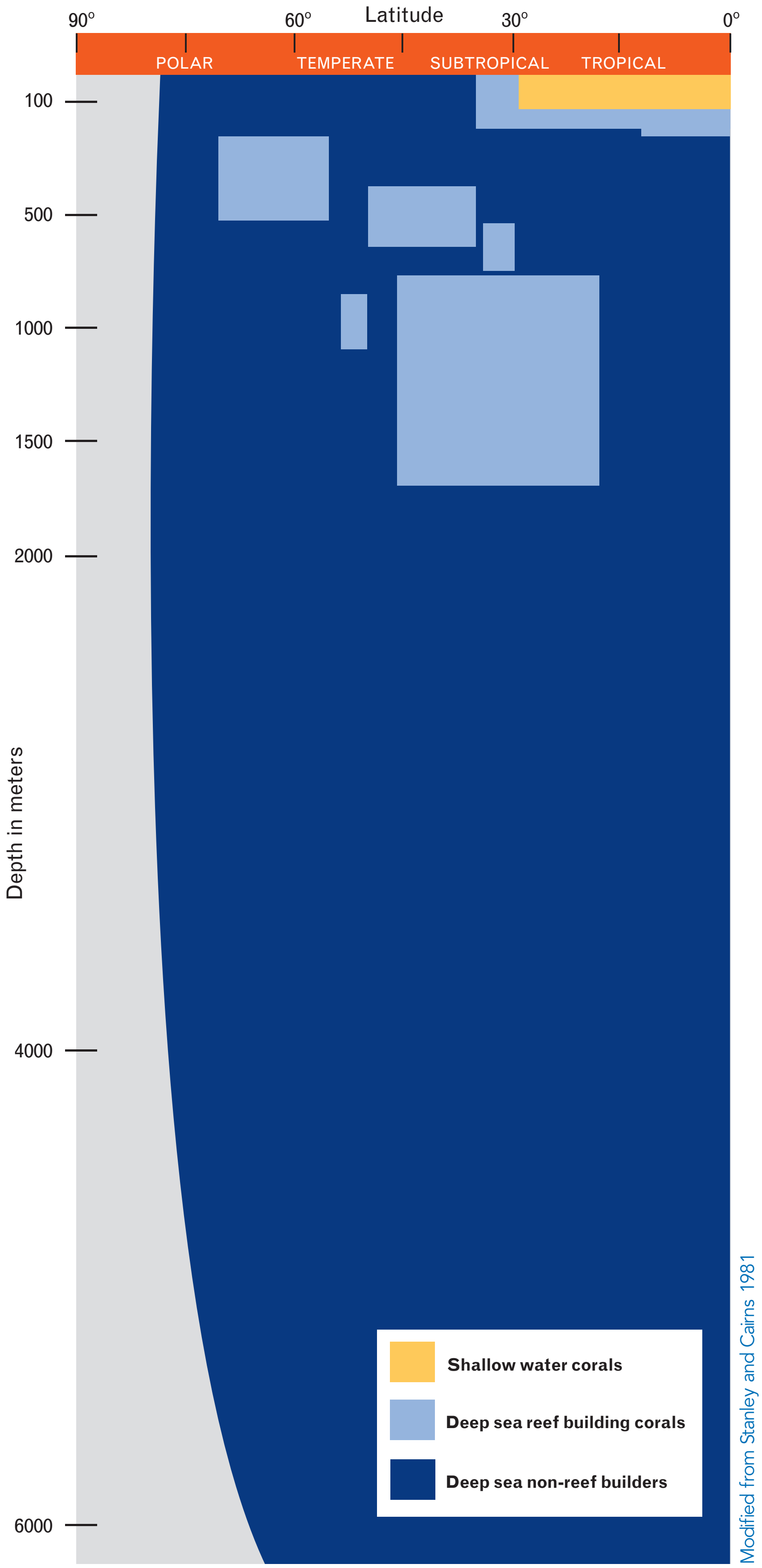


Black smoker at a hydrothermal vent

Paragorgia seafan

1. NOAA; 2. Richard Lutz, Rutgers University; 3. NMFS/MBARI

WHERE CORALS GROW



Modified from Stanley and Cairns 1981

Tropical corals rely on the sun and are limited to shallow waters and low latitudes. Deep sea corals have been discovered at a wide range of depths in subtropical, temperate, and even polar latitudes. Both tropical and deep sea corals can build reefs.[12]

Corals are well known for harboring an enormous diversity of life. Less well known is that two-thirds of all identified coral species live in deep, cold and dark waters.[11] Unlike tropical corals, which live symbiotically with algae and so obtain some of their energy directly from sunlight, those in deep and cold waters must capture all of their food from the surrounding water. They are thus capable of living far below the reach of the sun's rays, some more than five and a half kilometers (5,630 meters) below the ocean's surface. They can also survive much lower temperatures – as cold as 30°F – allowing them to range as far north as the Norwegian Sea, and as far south as the Ross Sea in Antarctica.[12]

Both tropical and deep water corals show great diversity in size, shape and color, from bleach-white cups no larger than a fingertip to crimson trees ten feet tall. Some are stony and hard, others are soft and sway with the current. Some build gigantic mounds reaching many feet from the seafloor,[13] several build smaller colonies, and still others are solitary.[14]

A. Lindner

Colorful coral landscape beneath the waves near Adak, Alaska, 150 meters deep.

Monterey Bay Aquarium Research Institute/MBNMS

Gorgonian seafan on the crest of Davidson Seamount near California, 1,200 meters deep.

Deep Water Reefs and Sea Fans

Deep water coral reefs, like shallow tropical reefs and old-growth forests, are truly ancient. Large *Lophelia pertusa* reefs are thought to be many thousands of years old.[15] One of the largest *L. pertusa* reefs discovered to date is about 300 meters deep in the waters off Norway. It is more than 13 kilometers long and about 400 meters wide, and some parts reach as high as 30 meters off the seafloor.[16] The deep water ivory tree coral, *Oculina varicosa,* builds extensive reefs similar in size, shape and structure to *L. pertusa.*[13] Found only off the southeastern United States, these reefs grow at about 1 centimeter per year,[17] and are likely to reach 1,500 years of age.[13]

Deep water gorgonian corals are equally remarkable. *Primnoa spp.* and *Paragorgia arborea*, more commonly known as red tree coral and bubblegum coral, respectively, can form great branching trees that reach many meters from the seabed. Using submersible research vessels,[18] scientists have observed corals that are 2 meters tall and 7.6 meters wide. Scientists and fishers have reported bubblegum trees more than 3 meters and a third of a meter at the base.[19] Growing less than 2.5 centimeters, some large bubblegum and red tree colonies may be several centuries old.[20,21,22]

Deep-sea coral communities often consist of many types of coral and other living habitat. For example, it is estimated that more than a hundred deep-sea coral and sponge species live in the North Pacific waters off Alaska.[23] Alaska is indeed a hotspot for corals, as the Aleutian Islands are thought to contain the highest diversity and abundance of coldwater corals in the world.[24] Furthermore, although thousands of different types of deep-sea coral have been described – including hydrocorals, sea fans, bamboo corals and black corals – scientists estimate that roughly 800 species of stony corals alone have yet to be discovered and described,[25] in addition to many of the animals associated with them.

Ecological and Commercial Importance

Deep-sea corals, sponges and other habitat-forming animals provide protection from currents and predators, nurseries for young fish, and feeding, breeding and spawning areas for numerous fish and shellfish species. *Lophelia* and *Oculina* reefs both harbor a variety of life as great as shallow-water reefs.[13,15] Rockfish, Atka mackerel, walleye pollock, Pacific cod, sablefish, flatfish, crabs, and other economically important species in the North Pacific inhabit coral and sponge areas.[18] Dense schools of redfish heavy with young have been observed on *L. pertusa* reefs off Norway,[26] suggesting the reefs are breeding or nursery areas for some species.[27] The dense and diverse Oculina Banks community supports large numbers of fish, including groupers, bass, jacks, snappers, porgies and sharks.[17] Studies support fishers' observations that the disappearance of corals influences the fish distribution in the area.[18,26]

Coral and sponge communities are a largely untapped resource of natural products with enormous potential as pharmaceuticals, nutritional supplements, pesticides, cosmetics and other commercial products.[28] Already, scientists have discovered more patented pharmaceuticals in marine sponges than any other group, including terrestrial plants.[29] Considering how few deep-sea invertebrates have been studied, the potential is enormous for discovering new drugs to treat ailments ranging from asthma to cancer.

A. Shepard National Undersea Research Program

Schooling anthiid fish over an *Oculina* coral reef habitat near Florida, 75 meters deep.

Richard Lutz, Rutgers University

Zoarcid fish swimming over a vent mussel bed on the East Pacific Rise off Mexico, 2,400 meters deep.

The energy captured by plants supports virtually all life on Earth, whether on land or in the sea. This is true even for life in the deep sea, which is almost entirely sustained by the algae and other organic matter that falls from the thin layer of surface waters where sunlight is bright enough for plant life to grow.

However, in the generally low-energy environment of the deep ocean, oases exist whose energy is derived from other sources. Cracks in the Earth's crust below the waves allow cold seawater to trickle down to the magma layer. Superheated water then rises from a crumbly vent or from cracks and fissures. Minerals fall out of the jet as it cools and give the plume the appearance of black or white smoke. Remarkably, these portals to the center of the Earth, known as hydrothermal vents, teem with some of the most unique, interesting, and mysterious creatures on Earth.

Life, but Not as We Know It

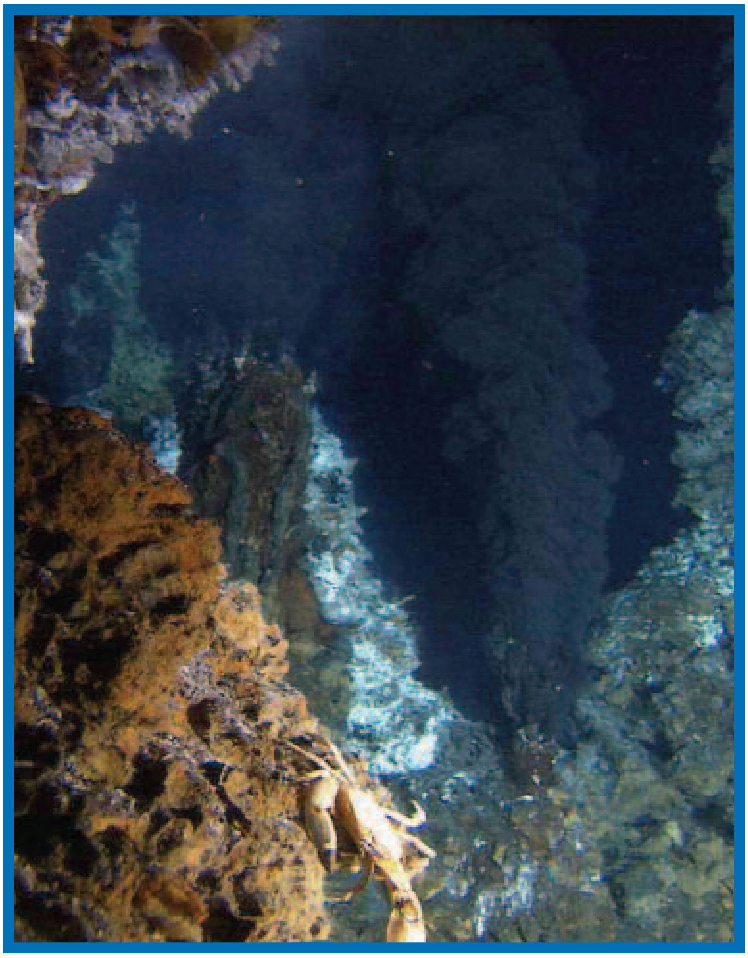
The hydrogen sulfide and methane emissions from vents are highly toxic to most life, yet provide energy for a remarkably specialized community of worms, crabs, mollusks, shrimp, anemones, soft corals and other fauna. Bacteria and primitive microbes called Archaea convert the sulfur-rich emissions into energy. The Archaea and free-living bacteria are directly fed upon by the other vent inhabitants. Other bacteria have formed elaborate relationships with other vent-dwellers such as mussels and clams. For example, some giant tubeworms a meter long have no mouths or digestive systems, and derive energy from the bacteria in their tissues, which in exchange receive protection by living within the worm.[43] The many trillions of bacteria found in these worms produce enough energy to allow their host to grow by almost 2.5 centimeters every ten days, making them the fastest growing marine invertebrate.[44] Another inhabitant of hydrothermal vents is the large Pompeii worm, which also probably gets much of its food from bacteria, this time attached to the outside of the worm's body. Many typically live together in large honeycomb-like colonies around vent openings from which floods superheated water in excess of 150°C.[9] These and other worms around these vents may well be the most heat-tolerant animals on Earth.

Of the more than 500 new species identified at vents since they were discovered more than 20 years ago, 90 percent are known only from vents. Many also have close relatives at other sulfide-rich sites, such as cold seeps, that are unknown from other deep sea environments. Hydrothermal vents are also home to holdovers from ancient times, fauna

Richard Lutz, Rutgers University

Vent shrimp and brachyuran crabs on the Mid-Atlantic Ridge, 3,350 meters deep.

with exceptionally ancient lineages. For example, while shallow water barnacles may have evolved 28 million years ago, and deep water barnacles 81 million years ago, vent barnacles appear to have originated 153 million years ago.[44] Indeed, the discovery of the Archaea has led some scientists to speculate that life on Earth may have originated around such vents.[45]



Richard Lutz, Rutgers University

Minerals in superheated water escaping the seabed give it the appearance of a 'black smoker.' East Pacific Rise, 2,400 meters deep.

Cold Seeps

Rich communities of specialist organisms also thrive where colder sulfide and methane-rich fluids bleed from the deep seafloor. Sources of these cold seep fluids may be groundwater, hydrocarbons, methane, or long-buried organic material such as whale skeletons.[43] A remarkable cold seep originates from rainwater in the Santa Cruz mountains. From there it enters a sandstone aquifer, and is released far undersea along the walls of Monterey Canyon.[46] This seep thus allows rainwater originating in the mountains to nourish the trees and plants there, while also directly supporting chemosynthetic tubeworm communities in the deep sea.

Relatives of the giant tubeworms found at hydrothermal vents have recently been discovered eating bone from a whale skeleton about 2,900 meters beneath the waves off California.[47] They too have bacteria in their tissues, in this case to digest bone fats and oils. Each female worm, the only ones found eating the bones, also contained 50-100 tiny males. The fats and oils provide energy for worm eggs and larvae, which are spread far and wide in hope of finding another whale carcass.

Richard Lutz, Rutgers University

Pompeii worms on the East Pacific Rise, 2,400 meters deep.

SEAMOUNTS

The ocean floor is sculpted with tens of thousands of submerged mountains called seamounts, underwater islands that rise steeply to more than a half-mile from the surrounding seabed. Either solitary or part of long chains, they usually form where a plume of magma rises from a stationary crack in the seafloor or where continental plates are separating and creating new ocean floor. As many as 100,000[30] seamounts may occur throughout the oceans, and they show considerable range in physical, geological and chemical conditions. This wide range of environmental conditions leads to a high diversity of life, and makes many of them highly biologically productive.

Most seamount summits are many hundreds of feet beneath the waves, but not all. For example, Bowie Seamount, located 175 kilometers off the western coast of Canada, rises from a depth of about 3,000 meters to within 25 meters of the surface. Water clarity is very good at the summit, which is covered in red and brown seaweed. However, with depth the light fades, and animals such as sponges, anemones, hydroids and bryozoans become more abundant.[31] The deepest known living plant, seaweed growing below 200 meters depth, is from a seamount.[32]

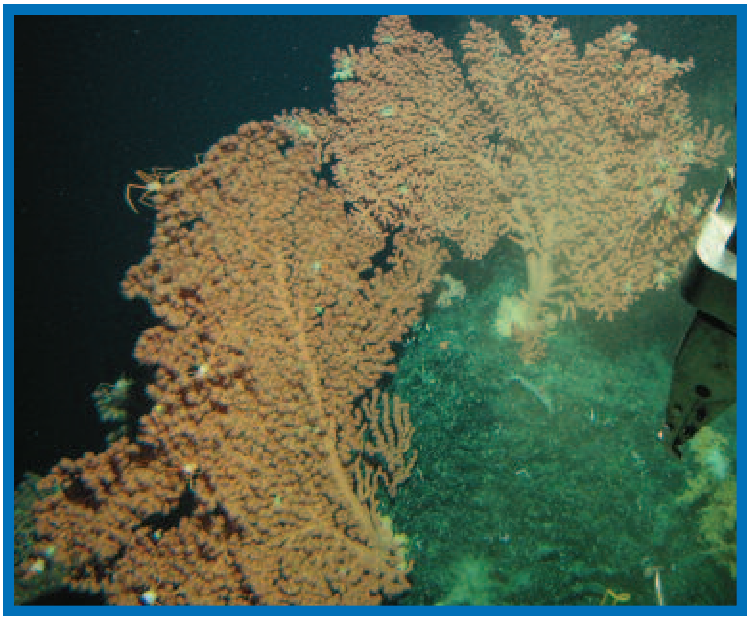
Seamount Life

Seamounts enhance the typically slow currents of the deep sea.[33] These faster currents sweep the rock surface clean of sediment and carry food for filter-feeding animals such as gorgonian, stony and black corals, and sponges, which often dominate the ecology of the area. [30] The largest global review of seamount invertebrate ecology to date found that corals and anemones were common on almost half of them, and sponges on about a quarter of them.[29] Some researchers call seamounts underwater gardens because of the prevalence of reefs, giant tree-like sea fans, and delicate corals and sponges.[29]

The animals found on seamounts provide foraging grounds and protection for many different fish, the types of which vary from region to region. Commercially exploited fish include orange roughy and oreos in the temperate South Pacific and North Atlantic, alfonsino in the tropics and subtropics, Patagonian toothfish (marketed as Chilean sea bass) in the subantarctic Southern Ocean, pelagic armorhead in the open North Pacific, and rockfish along the continental slopes of the Pacific and North Atlantic. The most comprehensive checklist of fish known from seamounts identified 535 species, though the total number is probably closer to 1,000.[34]

NIWA (New Zealand)

Stony coral reefs on small seamounts on the Chatham Rise, New Zealand, at about 1,000 meters deep.



NOAA, WHOI, the Alvin group, and the 2004 Gulf of Alaska Seamount Expedition science party.

Galatheid crabs in the branches of seafans on Pratt Seamount, just outside of US waters off the Alaskan coast, 900 meters deep.

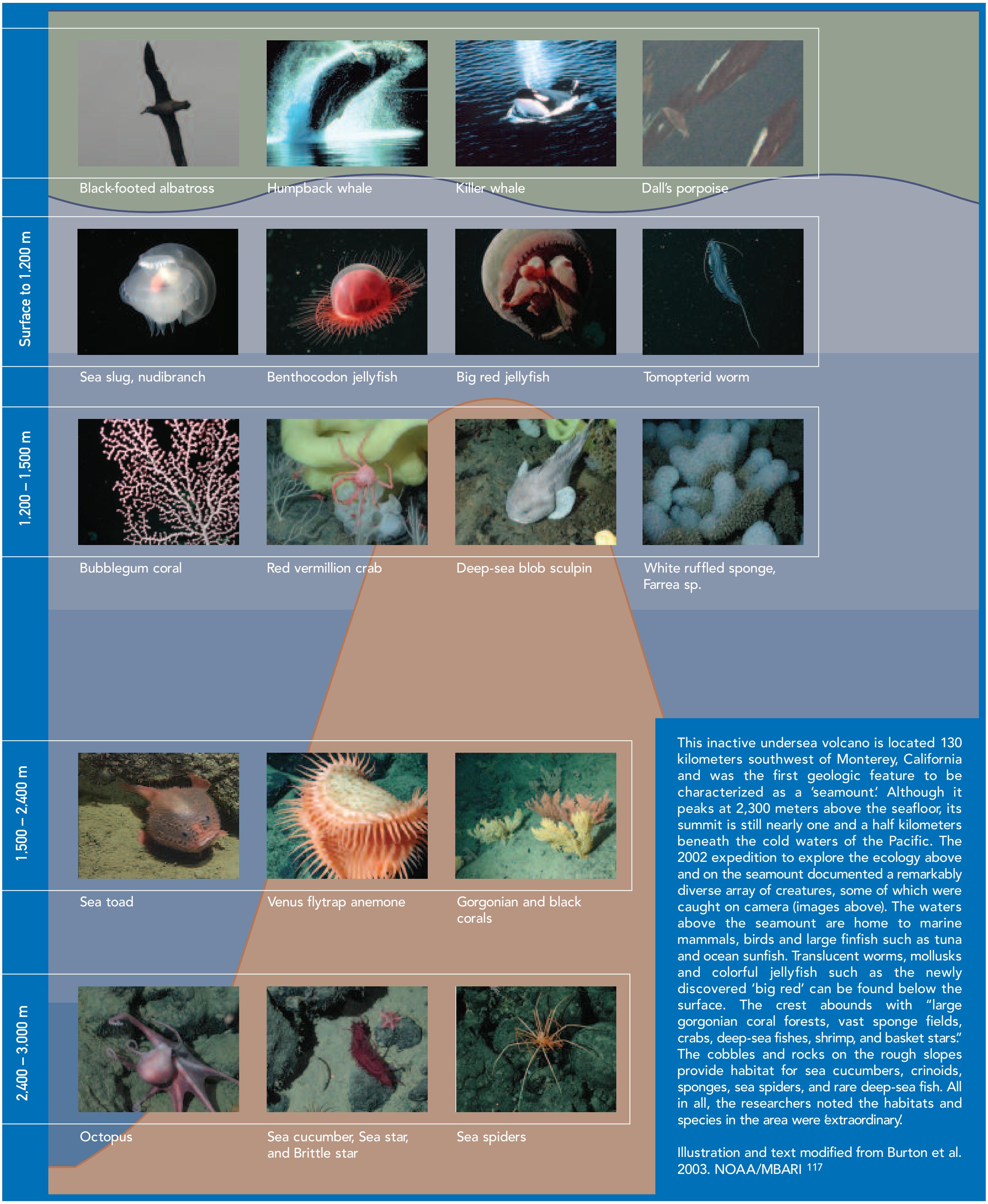
Seamounts also appear to be important for top predators, some of which concentrate their mating and spawning above them. The Formigas Bank in the northeast Atlantic attracts groups of pilot whales, and bottlenose, common, and spotted dolphins.[35] The highly productive waters above Davidson Seamount, located 120 kilometers off the coast of California, teem with a wide variety of fauna, including albatross, shearwaters, sperm whales, killer whales, albacore tuna, and ocean sunfish.[36]

Seamounts Harbor New and Unique Species

The earliest review of seamount species found that 12 to 15 percent of all species recorded on seamounts were likely unique to those areas.[37] Since then, several major studies have uncovered higher rates of unique species: More than 30 percent from New Caledonian[38] and Tasmanian seamounts,[33] and 44 and 52 percent of fishes and invertebrates respectively from Chilean seamount chains.[39] Other studies found less than 10 percent of fish species were unique to seamounts in the North Atlantic[40] and Hawaii,[41]but overall the initial estimate of 12 to 15 percent is likely too low.[29] Furthermore, new species have been found on virtually all seamount explorations to date – at least 50 percent of the 2,000 species identified so far during the New Caledonian seamounts studies are new to science.[30]

Seamounts may also act as refuges for species that have disappeared elsewhere – ‘living fossils,’ thought extinct since the age of the dinosaurs, have been found on New Caledonian seamounts.[42] Because scientists have sampled only a small fraction of seamounts, they are likely to discover many more new species.[29]

DAVIDSON SEAMOUNT



This inactive undersea volcano is located 130 kilometers southwest of Monterey, California and was the first geologic feature to be characterized as a 'seamount.' Although it peaks at 2,300 meters above the seafloor, its summit is still nearly one and a half kilometers beneath the cold waters of the Pacific. The 2002 expedition to explore the ecology above and on the seamount documented a remarkably diverse array of creatures, some of which were caught on camera (images above). The waters above the seamount are home to marine mammals, birds and large finfish such as tuna and ocean sunfish. Translucent worms, mollusks and colorful jellyfish such as the newly discovered 'big red' can be found below the surface. The crest abounds with "large gorgonian coral forests, vast sponge fields, crabs, deep-sea fishes, shrimp, and basket stars." The cobbles and rocks on the rough slopes provide habitat for sea cucumbers, crinoids, sponges, sea spiders, and rare deep-sea fish. All in all, the researchers noted the habitats and species in the area were 'extraordinary.'

Illustration and text modified from Burton et al. 2003. NOAA/MBARI [117]

Photos: MBNMS/MBARI

Not to scale. Approximate depths.

DEEP SEA FISHES

The ocean is undoubtedly the realm of the fish. Marine fishes dwell at all depths, from the shoreline to the deepest waters of the oceanic trenches. Many of the well known shallow water fish have relatives in the deep sea. For example, of the nearly 1,000 species of bottom-dwelling fishes that have been pulled up by trawls from the deep sea,[9] the most abundant are the grenadiers,[9] odd-looking relatives of cod. Indeed, the deepest dwelling fish discovered to date – a deep sea brotula, found in the Puerto Rican Trench at a depth of 8,200 meters[48] – is also distantly related to cod.

The relationship between cod, the brotula, and grenadiers would not be clear to the casual observer however. The Atlantic cod, the relatively large, muscular, streamlined fish that formed a cornerstone of both Northern European and American diets for centuries, is perhaps the definitive 'fish' to many Northern peoples. Grenadiers, on the other hand, look more like huge tadpoles. They have a large head and eyes and a bulbous body, completed by a long, slender tail. Their peculiar body shape, well described by their other common name – the rattails – is likely an adaptation to a relatively low food supply. Many deep-sea fish have reduced skeletal and muscular mass, slower metabolism and slower growth rate to reduce energy consumption, apparent adaptations to a lifestyle where the next meal is uncertain, while the chance of being preyed upon is also relatively low.[49]

Paul Yancey, Whitman College, Washington

Grenadiers are commercially landed and are distributed throughout the world's oceans.

If the roundnose grenadier seems strange, then many other deep sea fish look decidedly frightening when seen up close. They include serpent-shaped species such as snipe eel and gulper eel – also known as pelican eel due to its huge mouth with an expanding gullet; viperfish – with extremely long teeth and a lower jaw longer than the head; and deep sea anglerfishes – with shapes, lures and habits straight out of science-fiction movies. Most however are mere centimeters long.

Common Blackdevil Anglerfish

Edith Widder/HBOI

Fangtooth

Dave Wrobel

Viperfish

Mark Norman/NORFANZ

Mark Norman/NORFANZ

Longnose chimaera pup. The elongated body of this scaleless relative of sharks may help it detect prey.

Light, Color and the Senses

Most deep-sea fishes living in the twilight zone between 200 and 1,000 meters have large, highly sensitive eyes to make use of the small amount of light that does penetrate to the depths.[50] Many fishes at these depths and below produce their own light through special organs, which may also help to attract a mate or lure prey, frighten predators or even to provide camouflage against the weak light from the surface. Lanternfish and some dragonfish and viperfish have rows of lights through their elongate bellies and some possess a chin barbel at the tip of which is a lighted lure used to attract unwitting prey. Fishers in the past have used the luminescent excretion from the light organs of softhead grenadiers to enhance baits used for cod fishing.[51] Biological light production is also used for defense; some deep sea squid and jellyfish squirt a glowing ink which gives them cover while they escape.

In other cases, fish have well-developed chemical and acoustic sensors, which provide improved senses like smell and hearing.[52] For example, orange roughy and some snailfishes possess a system of acoustic pores on their heads and sides to sense movements and vibrations in order to identify the movements of both predators and potential prey.[53,54] This 'hearing' array is shared by other deep-sea fish, such as seafloor-dwelling chimaeras, eels, and grenadiers, many of which have elongated bodies, an adaptation which improves the precision and range of the sense.[1] Other fish rely on touch, such as the tiny-eyed tripodfish, which 'stands' about a foot from the seabed on sensitive fin rays.[1] Yet, many fish on the deep seafloor still have large, functional eyes, most likely because of the large variety of organisms that produce biological light, such as sea lilies, brittle stars, and sea cucumbers.[1]

Living in darkness also has its benefits. Many deep sea denizens are colored so that they are, in effect, invisible, enabling them to better avoid predators that rely on sight to catch prey. Transparent animals other than fish are common, as light simply passes through them without reflecting or creating a shadow.[55] Of all the colors that together make up daylight, red is the first to be absorbed by water, while blues and greens penetrate much deeper. Therefore, while most deep sea fish are blackish in color, some, like the orange roughy, alfonsino, and some rockfish are a striking crimson color, good camouflage in waters with no red light.[1]

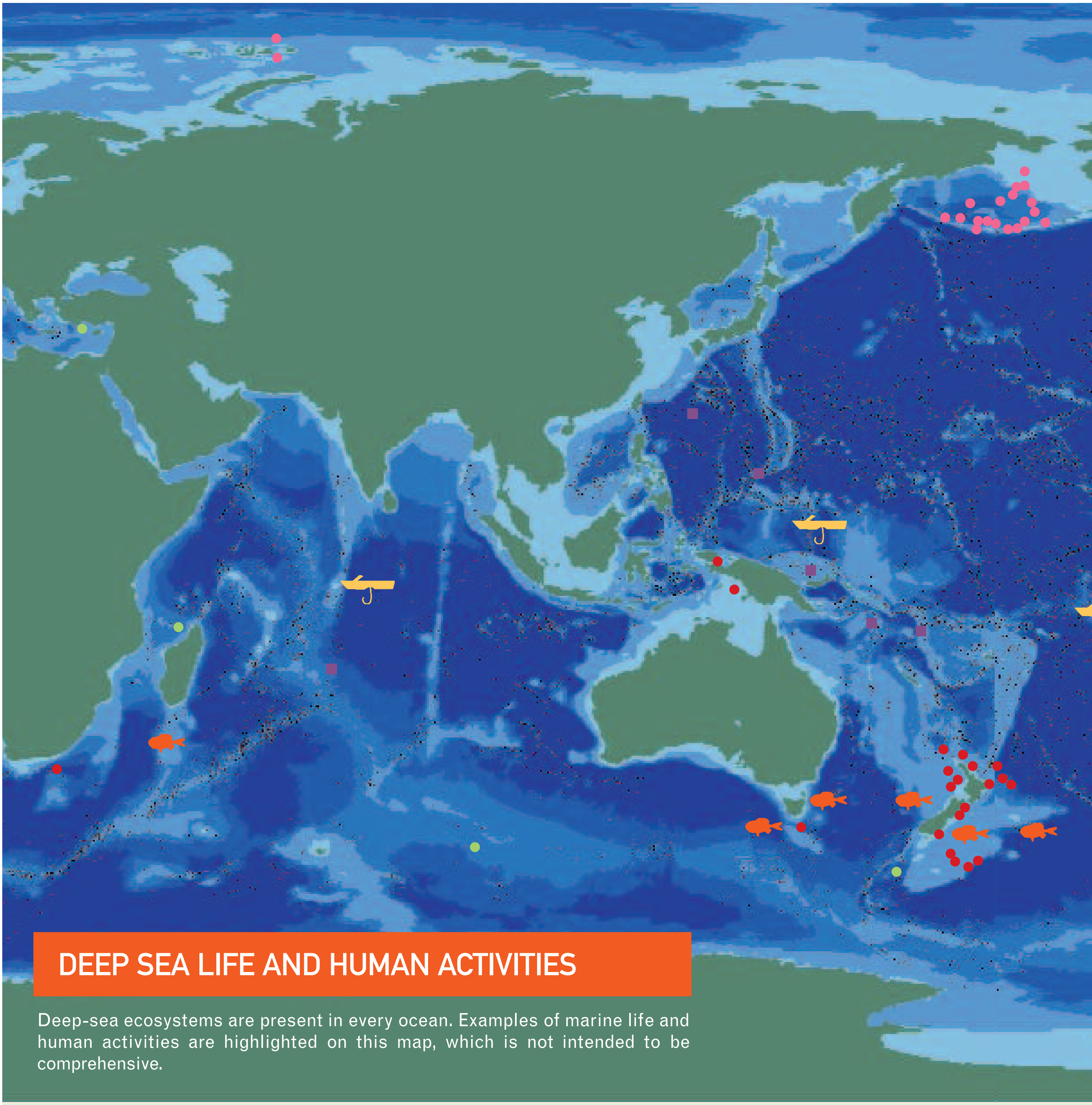
Lifestyle, Longevity and Reproduction

Many deep sea fish are exceptionally long-lived: Blue ling and Atlantic argentine can live between 30 to 35 years, roundnose grenadier more than 60 years,[56] the sablefish 114 years, orange roughy between 125 and more than 150 years,[57] and rougheye rockfish more than 200 years.[58] Even mollusks, including clams little bigger than a thumbnail, can live for more than 100 years.[44] Death from natural causes in the deep sea is typically low, and growth is often very slow. Furthermore, the age when reproduction begins is often later in deep sea fishes compared to shallow water fish. For example, roundnose grenadier begin reproducing at 14 to 16 years,[59] and orange roughy not until they are 20 to 30 years old.[60] Some deep sea fish, such as the tripodfish and lizardfish, encounter potential mates so rarely that they develop both male and female organs at the same time, allowing for self-fertilization if all else fails.[1]

The relative lack of food in the majority of deep sea is most likely one of the most important factors leading to the specialized adaptations of deep-sea fishes. In shallow water ecosystems food energy is often abundant, leading to many fish species with fast growth rates, early breeding, high natural death rates, and many offspring – and hence large populations that can replenish themselves relatively quickly. Such energy-rich ecosystems support large top-of-the-food-chain predators such as seals, sea birds and whales. Very few large predators forage in the deep, however, perhaps an indication that there is simply not enough energy to support them.[1]

Mark Norman/NORFANZ

Alfonsino catch from deep waters off New Zealand.

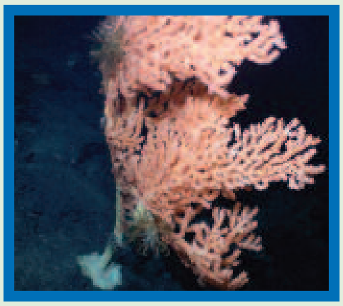


DEEP SEA LIFE AND HUMAN ACTIVITIES

Deep-sea ecosystems are present in every ocean. Examples of marine life and human activities are highlighted on this map, which is not intended to be comprehensive.

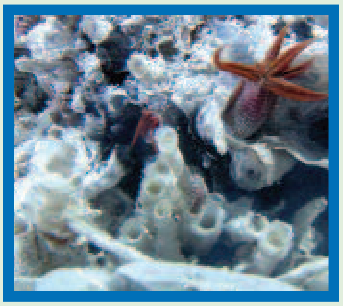
● Bubblegum corals

● Oculina corals



● Lophelia corals

● Other or unspecified coral communities



■ Hydrothermal vents

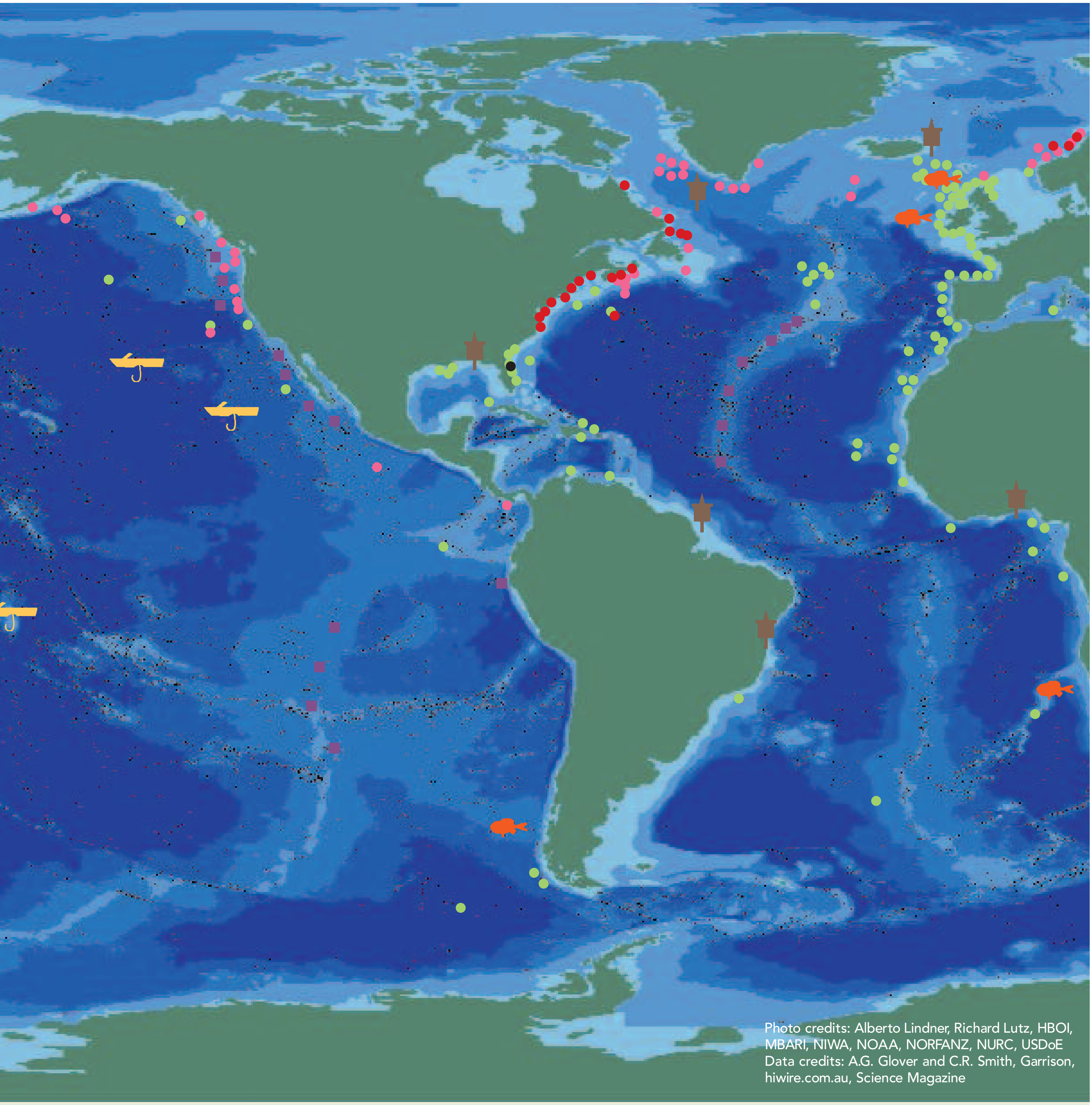


Photo credits: Alberto Lindner, Richard Lutz, HBOI, MBARI, NIWA, NOAA, NORFANZ, NURC, USDoE
Data credits: A.G. Glover and C.R. Smith, Garrison, hiwire.com.au, Science Magazine

Seamounts

Orange Roughy fishery location

Marine mineral extraction and exploration

Gas and oil exploration

Fishing is the most pressing threat to deep sea ecosystems. "The deep sea fishery really should not be considered a fishery at all. There is a much stronger analogy to a mining operation wherein an ore body is exploited to depletion and then new sources…are sought. And the deep sea fishery will remain a mining operation as long as ultimate technology is employed as the main tool in its prosecution."[1]

FISHING

D**eep water fisheries** began in earnest in the 1960s and 1970s, coinciding with declines in more traditional shallow-water fish populations.[60] The development of improved fishing technologies such as stronger net materials, more powerful engines and winches, and better fish-finding electronics enabled these fisheries to expand into deeper and deeper waters. Commercial trawling is the most pervasive of all human activities in the deep sea,[61] and is carried out on the continental slope, seamounts and deep coral reefs in virtually all oceans.[62] Indeed, some 40 percent of the world's trawling grounds are in waters deeper than the continental shelf,[63] from depths of 200 to 1,800 meters.[16]

In the early days of deep water fishing, the majority of species found both on seamounts and slopes were caught on the slope, but an increasing fraction is now being caught from seamounts. Indeed, fishing has driven slope populations of some species so low that they are now considered predominantly 'seamount' species,[64] although very few commercially caught deep sea fish are found only on seamounts.

Vulnerable to Overfishing

Sufficient information for sustainable management is not yet available for the vast majority of the known 535 seamount fish species. Scientists do not have enough information to measure the resilience to fishing for 75 of the 151 species that are currently exploited. For the other 76, enough is known to suggest that over half have 'low' or 'very low' resilience to fishing.[34] Catching these fish makes little economic sense[34] – they simply cannot withstand heavy fishing pressure. **In fact, research suggests that, for seamount fish, catching more than 5 percent of the fish in each population is likely to be unsustainable in the long term, whether they are currently fished or not.**[65] Because a much higher catch is needed for economic viability, a "number of seamount populations have already been depleted. More will be depleted and some will go extinct if fishing on seamounts continues at current, or even more moderate levels."[65] Indeed, from an economic standpoint, "it is more profitable to catch and sell all of the stock and then move on to exploit other resources." [34] Unsurprisingly, this 'boom-bust' approach, more akin to mining than fishing,[1] characterizes many seamount and other deep sea fisheries today.[64]

In early deep water fisheries, such as those for Pacific Ocean Perch and pelagic armorhead, the lack of management was a primary reason for the crash of the fish stock.[66] Unfortunately, contemporary management of deep water fisheries, where it exists, is usually based on experience in shallow water fisheries. Because there are considerable differences between the physical and biological diversity of the continental shelf and slope,[67]many deep sea fisheries still collapse today, even those that are actively managed.[66]

Orange Roughy

Orange roughy are exceptional in several ways. They are among the oldest living animals on the planet, even by deep sea standards. Furthermore, spawning episodes occur every one to two years, and most are unsuccessful in replenishing the population.[66] Both of these factors make them more vulnerable to fishing and thus complicate management.

Orange roughy is one of the most heavily exploited fish in the deep sea. Approximately 30 major orange roughy fisheries exist in the waters off New Zealand, Australia, Namibia, Chile, and in the northeast Atlantic.[68] Over two thirds of the fish (expressed by weight) in nearly half of these fisheries may already have been removed from the ocean by fishing, and in all the others but one the current status of the stock is unknown.[68] In Namibian waters, fishers removed 90 percent of known orange roughy in six years.[69] More than 85

Mark Norman/NORFANZ

One of the major exploited deep sea species, the orange roughy can live for 150 years.

percent of the fish in the South Pacific orange roughy fisheries off Australia and New Zealand were caught and brought to land by 2002.[70] **The maximum annual catch believed to be sustainable for these fisheries is only about 1 to 2 percent of the fish in each population, whether currently fished or not.**[71] In the northeastern Atlantic and around New Zealand, many aggregations of orange roughy have been depleted, and catch rates have only been maintained by the discovery and catch of previously unfished aggregations.[72]

Other Deep Ocean Fisheries

Many other commercially important deep water fishes – such as blue ling, roundnose grenadier and the pelagic armorhead – have shorter life spans and reproduce more quickly than orange roughy, and so have been considered better able to withstand intense exploitation. However, experience shows that these species, too, are vulnerable to excessive fishing .

The roundnose grenadier fishery in the North Atlantic started in about 1964, grew enormously during the late 60s, and spiked in 1971 at 80,000 metric tons.[67] The very next year the catch dropped by two thirds, and has dwindled since then. Thirty years after the largest catch, the fishery is showing few signs of recovery. [67] Pelagic armorhead from seamounts northwest of Hawaii were heavily fished during the late 1960s and early 1970s, and still have not recovered.[73] The International Council for the Exploration of the Sea found that many deep water fish populations in the North Atlantic are heavily exploited and some, including blue ling populations,[60] are severely depleted.[74]

Unfortunately, this pattern is common for deep sea slope and seamount fisheries. **On average, directed seamount-only fisheries collapse just four years after the largest catch** (eight years for other deep water fisheries), and recovery is many times slower than for a typical shallow water fishery.[64]

Seamount Fisheries

Most of the commercially valuable species of deep sea fish, including orange roughy, alfonsinos, oreos and pelagic armorhead, aggregate on and around seamounts.[65] Bottom trawls are the most effective method for catching gregarious species, and accounted for about 80 percent of the high seas catch in 2001.[75] In fact, some 40 percent of the world's trawling grounds are now on the continental slope and on seamounts,[63] to depths of more than 1,800 meters. Today's trawling technologies can reach an area of the oceans roughly the size of all the Americas and Europe combined.[76] The mouth of a bottom trawl net, the largest of which can swallow two Boeing 747s, is held open by two metal trawl doors. In addition, trawls that are to be used for fishing over uneven, rocky ground, like coral and sponge habitat, are rigged with large metal or rubber balls that are strung along the lead cable like beads. Trawl gear rigged like this can weigh over nine metric-tons, and is capable of moving 16-metric-ton rocks.[77] The combined direct and collateral effects of trawling can be particularly devastating to stable, structurally complex habitats like many of those fished upon by deep sea and seamount fisheries.[78]

AFMA

Catch of orange roughy from deep Australian waters.

Deep Sea Sharks

Nearly 35 percent of shark and ray species live in the deep sea. Fisheries for these species were almost non-existent before 1990,[80] but they are now becoming a more frequent target for directed fisheries. They are also caught incidentally in large numbers in other fisheries. Due to their slower growth and reproductive rates,[81] they are even more vulnerable to over-exploitation than sharks living in shallower waters (which are generally considered highly vulnerable). For example, the leafscale gulper shark may live 21 – 70 years, and the birdbeak dogfish for 11 – 35 years; both are caught in European fisheries.[82]

In the Northeast Atlantic, sharks may have declined more than any other species group.[83] Fishing for deep water sharks in the Rockall Trough and Porcupine Seabight in the northeast Atlantic in waters as deep as two and a half kilometers targets the leafscale gulper shark and the Portuguese shark. The number of sharks caught and brought to the dock in this area has risen almost twenty-fold in less than 10 years.[82]

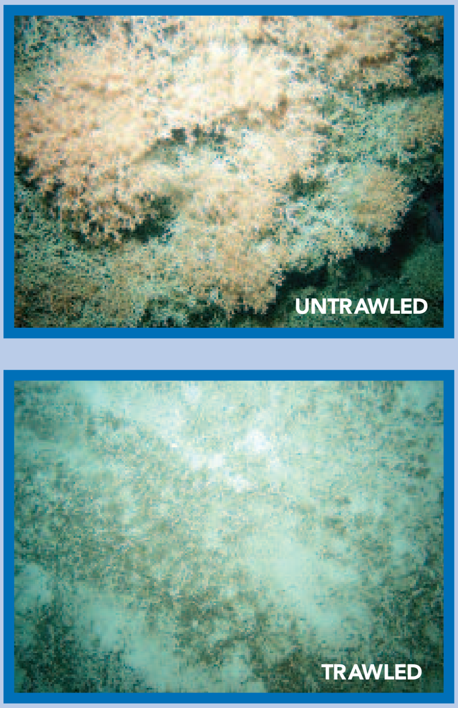
The ample evidence of problems caused by deep sea fisheries have led some scientists to conclude that “there is probably no such thing as an economically viable deep water fishery that is also sustainable.”[79] Others suggest that the only type of sustainable deep sea fishery possible is one that is on a very small scale, likely emphasizing a small quantity of high quality fish.[1]

Damage to Corals, Sponges and Other Living Habitat

The most visible effect of deep water trawling is on the seafloor itself.[60] **Trawling is the single largest threat to slow-growing seafloor animals such as corals and sponges,[85] and is likely to cause widespread ecological changes and reductions in the diversity of life at all depths.**[61]

Researchers in Tasmania, Australia have studied the effects of fishing by comparing several fished and unfished seamounts.[33,86] They found substantial damage to corals as a direct result of trawling for fish such as orange roughy and oreos. Heavy fishing had effectively removed all reef habitat; the most heavily fished areas resulted in habitats with more than 90 percent bare rock. [87] The authors note “virtually complete loss of this [coral] community…is consistent with other studies of the impact of trawling on reefal or other [seafloor] communities.”[60] **On seamounts in New Zealand waters a similar pattern emerges – researchers have documented close to 100 percent coral cover on unfished seamounts compared with two or three percent on fished seamounts.**[88] Furthermore, the fished seamounts in Tasmanian waters had 50 percent fewer species and seven times less biomass than unfished seamounts.[89]

Photographic surveys off Norway, Ireland and Scotland have found giant trawl scars up to four kilometers long in waters 200 to 1,400 meters deep.[90, 91] The deep sea coral reefs damaged by these trawls are estimated to be around 4,500 years old.[91] In Alaskan waters, the U.S. government estimates more than three million pounds of corals and sponges were removed from the seafloor between 1997 and 1999 by commercial fishing, roughly 90 percent of that by bottom trawlers.[92] **The amount of coral removed from seamounts by New Zealand trawlers targeting orange roughy was more than three million pounds for 1997-1998 alone,** though the quantity caught dropped considerably in later years as fishers trawled over the same spots. During these years, a single New Zealand trawl brought up 14,000 kgs of coral, while one Australian trawl during 2000 – 2001 caught an astonishing 45,000 kgs of coral, the main species caught on this trip.[93] In Norwegian waters, scientists estimate that between one third and one half of the deep water reefs have been damaged or destroyed by trawling.[26] Ninety percent of the extraordinarily diverse and productive *Oculina* reef habitat in the Atlantic off Florida, first described less than three decades ago, has already been damaged or destroyed. Researchers estimate that only an 8-hectare patch of undamaged *Oculina* reef remains in the world, a patch so small that a “trawler could easily destroy it in a single night.”[94]



Both photos: NIWA New Zealand

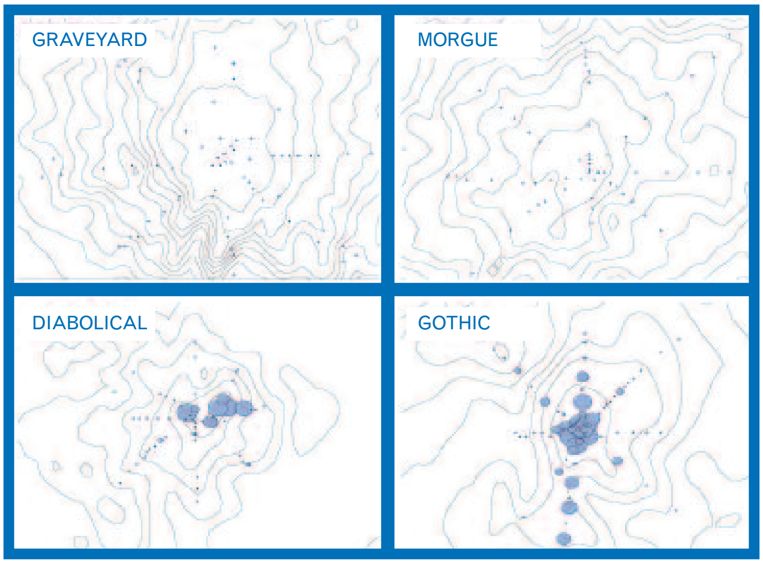
Comparable areas of trawled and untrawled stony coral reef on Chatham Rise seamounts near New Zealand. Heavy trawling in the area has removed virtually all coral on some seamounts.

Joe Schulack

Illustration of bottom trawling.

Due to the slow growth and uncertain success of reproduction in deep sea coral and sponge habitats, recovery may be on the order of centuries.[85] As these animals provide living habitat to other species, their loss could trigger domino effects on much of the local ecology of the area.[29] Furthermore, species extinction is a clear risk, since so many animals are found only on specific seamounts or seamount chains, some of them ‘living fossils.’[29]

Several governments have reacted to reports of cold-water coral destruction by trawlers. The United States closed the Oculina Banks to trawling in 1984, and recently extended the protections indefinitely. Australia instituted a temporary



Bird's-eye diagrams of four seamounts at similar depths on the Chatham Rise off New Zealand, named for the quantity of gear lost by fishermen. Blue circles indicate the coverage of coral seen in each photo, with larger circles indicating more coral. All photos were taken by a sled camera towed three meters above the seamount. Graveyard and Morgue, both heavily fished seamounts, showed less than two or three percent coral cover. In contrast, 100 percent coral cover was often seen in the photos taken over the unfished seamounts Diabolical and Gothic. From Clark and O'Driscoll. 2003.[88]

protected area to research the effects of an orange roughy fishery on 12 seamounts in 1995, which was then made permanent in 1999.[33] Norway created Europe's largest deep sea coral protected area in 1999, and has since banned trawling in four additional reef areas. Scotland and Ireland have recently won protections for several of their deep water *Lophelia* reefs from the European Union. New Zealand has protected 19 seamounts as part of ongoing research into their importance, and Canada has recently restricted bottom trawling in two small areas off Newfoundland and British Columbia. These moves are promising, but the vast majority of deep sea coral areas are still open, both in national waters and on the high seas. Roughly 47 percent of seamounts are found in national waters; far fewer than five percent are protected.[95] **For the 53 percent of seamounts on the high seas, there are virtually no protections at all from bottom trawling.**[95]

Dirty Fishing

Orange roughy, oreos, alfonsinos and Patagonian toothfish and a few other seamount dwellers are unusual among deep sea fish. In order to maneuver through the fast currents that wash over seamounts, they are robust and deep-bodied, with the firm flesh favored by consumers.[60] However, many deep sea fisheries catch a variety of different fish species and other animals which have soft, watery flesh, undesirable traits for either direct consumption or for conversion to fishmeal. The poor marketability of the majority of deep sea fish results in large quantities being simply thrown back over the side.[96] This 'dirty fishing' is a serious problem in many of the world's fisheries, but is a particular problem in the deep sea because the changes in pressure and temperature kill or mortally injure nearly all of the fish before they even reach the surface.[97] Consequently, virtually all fish thrown back overboard are already dead or dying.

Unfortunately, there is little good data on discards from deep sea fisheries.[98] Furthermore, observers rarely record fish with no economic value, which, for the deep sea, is most of them. However, studies indicate that levels of discards are as high in deep sea trawl fisheries as in many shallow-water ones. For example, roughly half of all fish by weight hauled up in the French fishery for grenadier in the northeast Atlantic are discarded, with discard rates increasing with depth.[99] The discarded catch in the deep water Mediterranean shrimp fishery amounts to between 20 and 50 percent of the total catch.[100, 101, 102]

Furthermore, deep sea fish that do escape a trawl net have more likely been injured by contact with the fishing gear than shallow-water fish. While shallow-water fish often have small scales and a mucus covering for protection, most deep water fish do not naturally need such adaptations.[103] Consequently, injuries and bodily damage from contact with fishing gears are very likely in deep sea fish, so that most that do escape, die. These escapees may amount to as much as three-quarters of the fish netted (45 percent by weight).[103] Thus, the number of fish actually killed by trawls (whether they are landed, thrown back overboard, or escape) is likely to be much higher than is currently presumed by most managers.

NIWA New Zealand

A small research sled filled almost solely with stony coral from New Zealand seamounts. While it is unlikely commercial trawls bring up only coral and no fish, recorded trips of trawlers in the area have shown a significant catch of coral, as high as tens of thousands of kilograms in the worst cases.

OTHER THREATS

Oil and Gas Exploration

Among potential threats to deep sea ecosystems, current oil and gas drilling activities are considered to have the greatest effect after trawling and other fishery activities.[104] The pace of oil and gas exploration and drilling in depths of more than 300 meters has accelerated rapidly in some areas in the last five to ten years. Of the approximately 25 mobile deepwater rigs working in the Gulf of Mexico in 1998, three were capable of drilling in water depths of up to 3,700 meters. An estimated 20 to 25 of these 'ultradeepwater' drilling rigs were in service worldwide in 2001.[105] Atlantic deep water prospecting is also occurring off Scotland, Brazil, and Namibia, and in some cases rigs are already producing oil. In all, more than 40 percent of the entire ocean is now within drilling depth.[106]

Oil and gas exploration and drilling could pose serious threats to fauna unable to avoid the area. These activities can directly crush and damage these creatures, and can affect their living conditions by increasing the amount of sand and grit in the water and altering essential currents and nutrient flows.[107] Drilling muds and cuttings from oil and gas exploration can be toxic to corals, and are known to cause death and alter feeding behavior in shallow-water varieties,[27] although the effects on deep water corals are unknown. Studies have shown that the presence of drilling muds can also inhibit the settlement of invertebrate larvae.[108] As with other activities, such as fishing, drilling wastes may pose a more serious problem in the deep sea than in shallow waters due to lower resistance among deep sea communities, as well as slower recovery rates.[104]

Pollution

Scientists long believed that chemicals and heavy metals of concern on land and in coastal waters, such as PCBs, DDT and mercury, would not reach the depths of the ocean. However, it is now known that they are almost ubiquitous, found in significant quantities in ocean waters from the Arctic to the Antarctic, borne on winds to places far removed from their source. Once in the ocean, they are carried by currents bound for the deep sea, or taken up by phytoplankton and accumulate in higher and higher concentrations with each step up in the food chain. Both the surface life itself and the creatures that rise from the depths at night to feed on it eventually die or are eaten, and their waste and bodies sink into the depths to be consumed by life on the deep seafloor. Thus, north Atlantic fish living in the twilight zone such as lanternfish, hatchetfish, viperfish and dragonfish have high levels of PCBs,[109] and deep seafloor dwelling species such as morid cod living at 2,000 meters have similar levels of PCBs and DDT as cod from the shallow shelf waters off Canada.[110] Recent research from the north and south Atlantic and Monterey Bay Canyon off California indicates that the deep sea might actually act as a sink for contaminants in the oceans, and that deeper-dwelling fauna may be even more contaminated with these chemicals than those that live close to the surface.[111] For example, in one study roundnose grenadier caught at 2,000 meters in the North Atlantic were more contaminated than those from 1,000 meters depth, and the deepest-dwelling fish caught, the lizardfish, was the most highly contaminated of all.[112] In recent years, PCB and DDT have been phased out in many parts of the world, but other similar chemicals still in use today are showing up in deep sea fish.[113] Whether contamination by persistent organic pollutants had, continues to have, or will still have significant impacts on the deep sea biology and ecology are unknown.


OCEANA

Two of the largest sources of mercury pollution are coal-fired power plants and mercury-cell chlorine factories.

Similarly, levels of mercury in some long-lived, commercially caught deep sea fish are high enough to raise questions about their suitability for human consumption. For example, orange roughy have over 0.5 parts per million of mercury (1 ppm = 1 mg/kg),[114] and alfonsino have levels as high as 0.96 ppm.[115] Because mercury levels also increase with age and size, larger specimens of these fish are often even more highly contaminated. The U.S. government recently warned that women of child bearing age and children should eat no more than one meal a week of albacore tuna, which carries an average of 0.34 ppm of mercury, and that those same consumers should not eat king mackerel (0.73 ppm), swordfish (0.97ppm) and shark (0.99ppm) at all.[114] Though no specific warning has yet been given for deep sea fish such as orange roughy and alfonsino, it seems clear that consumers should be similarly concerned.

Mineral and Hydrate Extraction

No commercial seabed mining operations currently exist in the deep sea, as the practice is not yet economically feasible. However, prospecting for precious minerals is underway in the deep Pacific waters off Central America, as well as in the southeast Pacific and the Indian Oceans. Such deposits are found from less than 300 meters to six and a half kilometers beneath the surface of the ocean, on rocky

MBARI

Hydrothermal vent community on the Gorda Ridge, off Oregon at about 3,000 meters depth.

outcrops from the continental shelf, on the tops of seamounts, and in abyssal sediment.[116] Valuable minerals such as copper, gold, cobalt and nickel are also present in the mineral precipitate from hydrothermal vents.

The environmental impacts of mining in the deep sea are not well understood. Organisms living on or near the seafloor will certainly be disturbed and may not recover for many years, in part due to the removal of the hard substrates on which recolonization depends. Other potential effects include algal blooms near the surface of the sea, and impacts on fisheries and migratory species like sea turtles. If mining becomes common in the future, it could pose the greatest and most widespread threat to deep sea communities of all human activities.[104]

Future threats from deep-sea mining could include extraction of methane hydrates, ice-like crystals made of water and natural gas that are buried beneath the seafloor. While there are many unknowns about the feasibility and potential consequences of releasing methane hydrates, the governments of the United States, Canada, Japan, Korea, and India have begun research into their potential as an energy resource. Uncontrolled releases in the geologic past may have led to abrupt climate changes, with significant implications for ocean ecosystems.[117]

Carbon Dioxide Sequestration

One of the "solutions" to the problem of carbon dioxide pollution of the atmosphere and global warming involves schemes to increase the amount of CO_2 absorbed by the oceans, either by 'fertilizing' the sea with iron, or by physically pumping CO_2 into the deep sea. In theory, the ocean could absorb our annual CO_2 emissions many times over. However, the interactions of physical, chemical, and biological processes that control the carbon cycle in the ocean are still poorly understood.[118] While the technical feasibility of such projects is being studied, the large scale ecological implications are receiving much less attention.

The goal of iron fertilization is to cause the increased growth of algae in areas where the lack of iron currently limits them, thus pulling more CO_2 from the atmosphere into the surface waters. The concept relies on the carbon to then fall into the deep sea through fecal pellets or dead organisms; otherwise it would simply be metabolized by surface organisms and released back into the atmosphere. Thus there could be massive ecological changes, both on the surface of the ocean due to changes in phytoplankton species composition, and in deep water. Increased organic matter in the deep sea could cause an increase in microbial activity that uses up the limited oxygen in areas of the deep sea, creating a dead zone in the same way that algal blooms do in shallower waters.

Pumping CO_2 into the deep ocean on the scale that would be necessary to get back to even twice the pre-industrial levels of atmospheric CO_2 would lower the pH in the oceans enough to have likely consequences for the ecology of the deep sea.[119] Increased seawater acidity could have profound effects on marine life in the same way that acid rain affects the life in freshwater lakes.[119] Furthermore, at depths below 3,000 meters, CO_2 would assume a liquid form and could pool like a lake on the seafloor,[120] effectively smothering any life that could not escape. Large dead zones, created as a result of either fertilization or CO_2 pumping, could cause "mortality sinks," in which animals killed by increased acidity or suffocation would decompose and attract scavengers into the area, which would die in turn. As a result, the effect on the deep sea could be far wider than the immediate area.[104]

Shane Anderson

Oil and gas drilling platforms are moving into deeper and deeper waters.

CONCLUSIONS AND RECOMMENDATIONS

Until recently, the deep sea remained the final frontier in humanity's incessant search for exploitable resources. Technology has now broken the barriers of depth and distance from shore, to create unsustainable trends in exploitation that are seriously damaging deep-ocean ecosystems. We now know that many of our land-based activities directly affect life in the deep sea in the same way they do every other ecosystem on Earth. Because destructive bottom trawling is by far the largest threat at present, we focus most of our conclusions and recommendations on it. However, other continuing threats (dumping, land-based contamination, and fossil fuel extraction) and future threats (seabed mining, methane hydrate extraction, and carbon sequestration) need better control, evaluation, and precautionary management before they are allowed to begin or expand into the deep sea.

Conclusions

- Seamount and other seafloor fish species are likely to be far more vulnerable to fishing than most shallow-water species. The maximum catch that is likely to be sustainable for seamount fish is a tiny fraction of the population. Because bottom trawling for a small number of fish is not economically viable, 'mining' of entire populations of seamount fish has become the norm.

- Seamounts, deep sea corals, hydrothermal vents and cold-water seeps support hotspots of life in the deep ocean. Because animals in these areas are often extremely long-lived and fragile, destructive activities such as bottom trawling can destroy decades or even centuries of growth. Recovery is not likely in our, or even our children's lifetimes – if ever.

- Seamounts and vents are often home to unique species found nowhere else on earth, leading to high likelihood of species extinctions if the areas are damaged. Some are also home to species thought extinct since the time of the dinosaurs.

- Because species such as birds, whales, dolphins and turtles congregate over seamounts, they may be important for successful migrations. The deterioration of seamount ecosystems could have adverse affects on the wider marine environment.

- Organic pollutants such as PCBs and DDT are found in high levels in many deep sea fish, and mercury is high enough in some to raise concerns over their suitability for consumption.

Recommendations

- The UN General Assembly should adopt a resolution calling for an immediate moratorium on high seas bottom trawling, until such time as effective, legally binding conservation and management measures to protect deep sea biodiversity and conserve and manage bottom fisheries have been adopted and implemented in accordance with international law.

- Individual governments should assess deep water ecosystems in national waters, and protect areas of high biodiversity and/or high vulnerability from the most destructive activities, particularly bottom trawling.

- An especially cautious approach, erring on the side of conservation, should be paramount in all planning and management decisions regarding deep sea resource exploitation. Similar precaution should be exercised pertaining to contamination by persistent bioaccumulative chemicals.

- Studies of the local and large scale ecological implications of projects such as iron fertilization, carbon dioxide pumping, methane hydrate extraction, and toxic waste disposal – and their implications for the health of marine life – are more important than studies to assess their technical and economic feasibility.

ENDNOTES

Acknowledgements

The authors wish to thank many individuals for their help with this report. Deserving of particular gratitude are Drs. John Gage, John Gordon, Tony Koslow, Daniel Pauly, and an anonymous expert, for their technical reviews. Much appreciated technical advice was also provided by Eric Annis. Additionally, thanks to those who kindly provided data, images and video: Drs. Stephen Cairns, Malcolm Clark, Rainer Froese, Randall Kochevar, Alberto Lindner, Richard Lutz, Don Michel, Mark Norman, John Reed, Don Robertson, Andy Shepard, Joe Siebenaller, Robert Stone, Ken Sulak, Kevin Sullivan, Edith Widder, and Paul Yancey; and Tamsin Allen, Tissa Amaratunga, Kim Fulton-Bennett, Erica Burton, Allison Mitchell, and Dave Wrobel. Finally, special appreciation to Kelsey Abbott, David Allison, Christina Cairns, Bianca DeLille, Phil Kline, Shikha Savdas, Margot Stiles and the entire team at Oceana.

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