22 May 2012
INTERNATIONAL DAY FOR BIOLOGICAL DIVERSITY
Marine Biodiversity

One Ocean
Many Worlds of Life

UNEP

Convention on Biological Diversity

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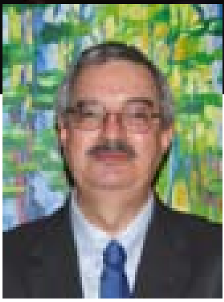

The International Day for Biological Diversity, on 22 May, is a special occasion to reflect on the role of biodiversity for our lives, and for all things on our planet. In 2012, the theme for the day is Marine and Coastal Biodiversity.

The survival of marine and coastal ecosystems and biodiversity is essential to the nutritional, spiritual, societal and religious well-being of many coastal communities. But even for the many millions of people who may not think that they have any strong reliance on the ocean, marine ecosystems and wildlife provide all kinds of benefits.

Fisheries provide over 15 percent of the dietary intake of animal protein. Many coastal environments provide protection for those farther inland from the ravages of the sea. Substances derived from seaweeds stabilize and thicken creams, sauces, and pastes, are mixed into paint and used to make paper and even in skin lotion and toothpaste. Many marine plants and animals contain a multitude of substances being used, or identified as being of potential use, in medicines. Tiny marine plants called phytoplankton release half of all oxygen in the atmosphere.

The protection of marine ecosystems, therefore, is crucial to human well-being. As part of its Jakarta Mandate on marine and coastal biodiversity, the Convention on Biological Diversity is committed to a series of specific goals that will, among others, develop, encourage, enhance and implement wide-ranging integrated marine and coastal area management (IMCAM) and includes a broad suite of measures at all levels of society.

At the tenth meeting of the Conference of the Parties to the Convention on Biological Diversity in Nagoya, Japan in 2010, governments agreed to a Strategic Plan for Biodiversity for the period of 2011-2020. This plan and its Aichi Biodiversity Targets, include several specific and relevant targets for marine and coastal areas. These address the sustainable harvest of fish and invertebrate stocks and aquatic plants, and the establishment of greater levels of protection for coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services. And by 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are to be minimized.

There is no question that these are ambitious goals. But they are necessary, for time is short. Even as we are continuing to learn much about the environments and wildlife that inhabit our seas and coasts, the threats they face are clear, and the solutions are available.

The longer the delay, the more difficult solutions become to implement.

I encourage you to work to save biodiversity, not only on the 22nd of May, but every day.

Braulio Ferreira de Souza Dias
Executive Secretary, Convention on Biological Diversity

Coral reef ecosystem at Palmyra Atoll National Wildlife Refuge, USA

flickr/Jim Maragos/U.S. Fish and Wildlife Service

Nudibranch (*Nembrotha kubaryana*), Philippines

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Summary

The ocean covers 71 percent of the surface area of the globe and constitutes over 90 percent of the habitable space on the planet. It contains the largest animals ever to have lived on Earth and billions upon billions of the tiniest: there are more living things in the sea than there are stars in the universe.

From sandy shores to the darkest depths of the sea, the ocean and coasts support a rich tapestry of life: shorebirds that stalk across mudflats in search of shellfish prey; alligators that ease their way through mangrove swamps; kelp forests that sway beneath the waves; polar bears that stalk seals across the sea ice of the Arctic; penguins that seek to evade seals in the Southern Ocean of Antarctica; and tiny photosynthesizing plants called phytoplankton that provide 50 percent of all the oxygen on Earth. Even on the deep seabed, there is a unique ecosystem that few humans have ever seen—supported by vents through which super-heated water and gases erupt.

People have lived near and fished from the ocean for thousands of years. Today, about 40 percent of the world's population lives within 100 kilometres of the coast; fisheries provide over 15 percent of the dietary intake of animal protein; toxins in some species may yield anti-cancer drugs and other pharmaceuticals potentially worth more than US$ 5 trillion; and coastal ecosystems provide services, including tourism and protection from storms, that have been valued at nearly US$ 26 billion annually.

Despite this long-standing connection to, and benefits derived from, marine and coastal biodiversity, it has not always fared well at human hands. Some species, from the great auk to the sea mink, are extinct; others, notably the great whales, have been hunted to fractions of their original populations. Commercial overexploitation of the world's fish stocks is so severe that almost a third of all fish stocks are being overexploited, and some 13 percent have collapsed completely. Between 30 and 35 percent of the global extent of critical marine environments such as seagrasses, mangroves and coral reefs are estimated to have

UNEP/Topham

been destroyed. Underwater noise is limiting the potential of whales and other marine animals to communicate with each other, plastic debris continues to kill wildlife that ingests and becomes entangled in it, and pollution from land is creating areas of coastal waters that are almost devoid of oxygen.

Added to all of this, increased burning of fossil fuels is affecting the climate, making the sea surface warmer, causing sea level to rise, and also increasing seawater acidity, with consequences we are only beginning to comprehend.

But there is hope. Around the world, species and populations are recovering with effort and intervention from communities and governments; large areas are being established as protected areas; and the Parties to the Convention on Biological Diversity (CBD) have adopted a series of specific targets that require stakeholders at all levels to work together to protect the biodiversity that lives in the ocean, for its own sake and for the benefits it brings to people worldwide.

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> **"From space, the planet is blue. From space, the planet is the territory. Not of humans, but of the whale."**
>
> HEATHCOTE WILLIAMS, WHALE NATION

Earth is a Water Planet

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Earth is the only planet in the known universe with liquid water on its surface and the only planet with life. Life originated in the primordial ocean where it has evolved for millions and millions of years. The ocean covers 71 percent of the surface area of the globe, a total area of more than 360 million square kilometres.[1] It occupies over 60 percent of the Northern Hemisphere and more than 80 percent of the Southern.[2]

The ocean constitutes over 90 percent of all habitable space on Earth; whereas on land, almost all life clings to the surface, in the ocean it is found from top to bottom, from the sunny surface of tropical seas to the cold, dark depths, thousands of metres below. Yet, from a planetary perspective, the ocean is a thin layer on the Earth's surface, thinner than the skin of an apple, and therefore inherently fragile and finite.

"How inappropriate to call this planet Earth, when clearly it is Ocean."

ARTHUR C. CLARKE

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The largest creature ever to have lived on Earth is in the ocean: the mighty blue whale, the largest known example of which measured over 33 metres from tip to tail and weighed more than 190 tonnes. At the other end of the scale, the smallest known fish in the sea is only 8 mm long and weighs less than 2 milligrams[3]. But even that is a giant compared to the bacteria and other similar-sized microorganisms that teem in the ocean; just one drop of seawater may contain as many as 350,000 of them, which means there are many, many more of them in the sea than there are stars in the entire universe[4].

Ocean life is almost as varied as it is plentiful. Seahorses, the males of which carry their young in pouches, thread their way silently among reefs and seagrasses. Sea otters roll onto their backs at the water's surface, opening shellfish by cracking them on rocks they rest on their stomachs. Humpback

Humpback whale (*Megaptera novaeangliae*)

flickr/panacheart

whales encircle schools of herring, herding them into place by blowing "nets" of bubbles before surging to the surface with their giant mouths agape. Sailfish, frequently cited as the fastest fish in the sea, race after their prey at speeds that may be as high as 110 kilometres an hour, swimming as fast as cheetahs can run. Octopuses change colour and pattern at will, blending into the background to avoid detection and then, when disturbed and frightened, turning a bright red and squirting a cloud of black ink as they propel themselves into the distance. Barnacles hitch rides on ships, whales and turtles. Wandering albatrosses extend their enormous wingspan and cruise above the sea surface for hours on end. Kelp fronds sway back and forth in rhythm with currents and tides. Sea stars devour shellfish in stomachs they extend outside their bodies. Sea anemones fire poison darts into any unsuspecting prey that swim or drift close enough to brush against their tentacles. Cleaner wrasses pick parasites from mouths and gills of grateful clients.

Grey seal pup (*Halichoerus grypus*)

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Polar bears stalk Arctic sea ice in search of seals. Snapping shrimp stun potential prey and putative predators with a loud bang generated by snapping shut an oversize claw. Anglerfish dangle lures above their open mouths, tempting unsuspecting victims to swim toward their doom. Marine bacteria may live for only hours, racing through life with enough rapidity that, in the words of one author, they can "produce multiple generations in the time it takes us to get a good night's sleep". Meanwhile, in the cool waters far below the surface, deep-sea corals survive for over 4,000 years[5].

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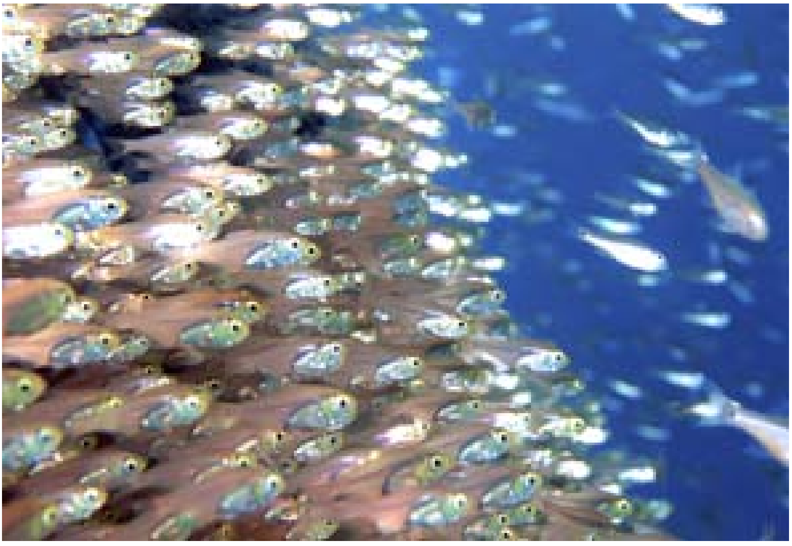
How Much Life in the Sea?

But exactly *how* varied is marine life? How many species of living things exist in the water along the coasts and in the ocean? From 2000 to 2010, an unprecedented worldwide collaboration by scientists around the world set out to try and answer that very question.

The Census of Marine Life involved 2,700 scientists from over 80 nations, who participated in 540 expeditions around the world.[6] They studied surface seawater and probed the deepest, darkest depths of the ocean, sailed tropical seas and explored ice-strewn oceans in the Arctic and Antarctic.

They found a shoal of fish the size of the island of Manhattan, and a massive "mat" of microbes covering an area of seafloor the size of Greece, thriving on hydrogen sulfide in a zone devoid of oxygen. They found carnivorous deep-sea sponges and sea cucumbers that walk along the ocean floor. They rediscovered a species of clam believed extinct since the 1800s and a species of shrimp thought to have disappeared during the Jurassic era, 45 million years ago. They documented previously unknown species, including a form of kelp in the shallow coastal waters of Alaska's Aleutian Islands, and a bizarre-looking deep-water crustacean whose claws are covered with fur-like bristles, earning it the name of "Yeti crab."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Blue-footed booby (*Sula nebouxii*), Galápagos Islands

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Coral reef, Belize

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By the time the Census ended, it had added 1,200 species to the known roster of life in the sea; another 5,000, assumed to be previously unrecorded, await official categorization. Excluding the likes of bacteria, viruses and the peculiar life forms known as Archaea, Census scientists concluded that the most diverse group of marine life is the crustaceans, such as crabs, lobsters, barnacles and krill, which comprise slightly less than 20 percent of all species in the ocean. By way of comparison, fish comprise approximately 12 percent of marine species, and a mere 2 percent are other vertebrates such as marine mammals and seabirds.

As for how many species there are in total—that's a question that still hasn't been fully answered, despite the magnificent achievements of the Census of Marine Life.[7] As Nancy Knowlton of the Smithsonian Institution, the leader of the Census's coral reef studies, put it: "At the end of the Census of Marine Life, most ocean organisms still remain nameless and their numbers unknown. This is not an admission of failure. The ocean is simply so vast that, after 10 years of hard work, we still have only snapshots, though sometimes detailed, of what the sea contains. But it is an important and impressive start."[8]

The estimated number of known marine species—the species that have been identified and the ones that have been documented but await classification—has increased as a direct result of the Census's efforts, and is now around 250,000. In its final report, the Census team suggested it could be at least a million[9]. Some think the figure could be much higher.

Looking closely at bubble anemones, delicate soft pink deep-sea octocorals at 1500 metres depth, brain corals and jellyfish, one can only be amazed by the incredible shapes and colours.

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In 2011, a team of scientists looked at all the known species on Earth, and the different categories into which they are grouped, and extrapolated an estimate of approximately 8.7 million species on Earth, 2.2 million of which live in the ocean. This would mean, they said, that 91 percent of all marine species have yet to be discovered—and that's after the huge effort put forth by the Census of Marine Life. In fact, they say, finding and describing future species is likely only to become harder, as our current inventory is filled with species that have large geographical ranges, are abundant, or are large and easy to see. Increasingly, if we want to find new species, we're going to have to look for "hotspots" of species in hard-to-reach places like the deep sea.[10]

Even if we assume that those scientists are correct and that there are more than two million species in the ocean, that still is only part of the story. Because when they say two million species, those researchers are referring to species as most of us generally think of them: plants and animals, for example. But such multicellular life forms comprise only a small fraction of the life in the ocean, both in terms of variety and abundance.

Imagine you could weigh all the life in the ocean and rank all the different types of life according to which weighed the most. You would probably expect that, added together, all the whales in the ocean might weigh the most, even though there are far fewer of them than there used to be, simply because whales are so massive. Or maybe fish would collectively be the heaviest grouping, because some of them—whale sharks, for example—are also pretty big and because there are so many fish in the sea.

If you did think that, you'd be wrong. When measured by weight, more than 90 percent of ocean life are microbes: invisible or virtually invisible to the naked human eye. Added together, all the microbes in the sea weigh more

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NOAA/Anna Fiolek

than *200 billion* African elephants.[11] As for how many different types of such microbes there are—well, the mind boggles. If, as some scientists report, a litre of seawater contains an average of 20,000 distinct types of microbial life, then the whole ocean could contain a figure so large as to be almost incomprehensible.[12]

Some of these microbes are highly abundant: a group of what is known as the Alphaproteobacteria is, in fact, the most abundant life form on Earth.[13] Others appear to be quite rare, but researchers are still puzzling over just what, in a microbial world, "rare" exactly signifies. Are some of these microbes keystone species within their ecological communities despite their low abundance? Or do they "do" little or nothing? Do some have low numbers but widespread distribution? Or are some, as appears may be the case, merely "biding their time", existing in low levels but able to flourish the moment environmental conditions change slightly in their favour? When it comes to such single-cellular organisms, researchers are still grappling with the basics.[14] [15]

The most abundant marine microbes are marine viruses. When most of us think of viruses, we do so only in the context of catching a cold—it seems slightly strange to think that they might exist in the ocean, but they do, and in great abundance. Notwithstanding their miniscule size, there are so many marine viruses that, if they were to be stretched end to end, they would reach farther than the nearest 60 galaxies.[16] They cause an estimated 100,000,000,000,000,000,000,000 infections in the sea *every second*;[17] these infections can lead, for example, to diseases that can kill large numbers of marine animals, but, arguably more significantly, they are continually culling the vast numbers of bacteria and other microorganisms in the sea, playing a vital role in shaping, and re-shaping constantly, the genetic pool, structure and diversity of the ocean's microbial communities.

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One Ocean, Many Regions

There are fundamental principles, linked to the fluid nature of the ocean, that strongly argue for the unity of the ocean: one planet, one ocean. Water moves and with it the organic and inorganic molecules and particles dissolved or floating in it. Neither pollution nor marine plants and animals respect the boundaries humans try to draw on the oceans.

Historically, sailors referenced the "seven seas"; modern oceanographers consider there to be five ocean basins—the Arctic Ocean surrounding the North Pole; the Southern Ocean encircling Antarctica; the Atlantic; the Pacific; and the Indian. But ocean currents circulate endlessly between them all, along what has been called "The Great Ocean Conveyer." And so, writers, sailors and scientists alike refer to our planet's great body of seawater not as the plural oceans but as the singular ocean.

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Many areas within the ocean are biodiversity hotspots

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Yet, within that ocean, there are of course many different areas, of greatly contrasting temperatures and depth, areas where sunlight bathes the surface almost constantly, areas where the sun disappears beneath the horizon for weeks and even months on end, areas so deep that sunlight has never reached and never will.

In the Arctic, the return of the sun in the spring prompts not only a melting of the ice that covers the sea in winter but also, along the edges of the retreating ice, huge blooms of microscopic algae[18] that prompt an explosion of life, as small Arctic cod feed on the algae, larger fish feed on the Arctic cod, ringed seals consume those predatory fish, and ringed seals, in turn, watch nervously for the sight of the region's alpha predator, the polar bear. Near the other end of the Earth, Kaikoura Canyon off the coast of New Zealand plunges deep below the ocean surface and, for reasons that may relate to the way its gentle sloping sides concentrate sediments and organic matter, is a haven for life that lives on the seafloor, supporting a marine ecosystem that includes one of the ocean's most elusive and mysterious creatures: the giant squid.[19] [20] To the west of Kaikoura, the Great Barrier Reef, the world's largest coral reef system, extends more than 2,000 kilometres along the northeastern


NOAA

coast of Australia and provides a home to at least 400 species of coral, 1,500 species of fish, 4,000 species of molluscs and 240 species of birds.[21] In the North Atlantic, the Sargasso Sea is an oasis of calm surrounded by ocean currents, where vast mats of sargassum seaweed drift gently, providing shelter for millions of small fishes, crustaceans and other life within their branches. Unencumbered by land and driven by powerful winds from the west, the Antarctic Circumpolar Current propels a seemingly endless series of low-pressure systems through the Southern Ocean, whipping up angry white-flecked waves that disguise the life that thrives on the cold, nutrient-rich waters, save for the occasional glimpse of a whale's hot breath or a determined petrel beating its wings furiously as it battles the wind and skims the water.

There are many different ways to define the ocean's different areas. For example, the world's coastal regions are divided into 64 Large Marine Ecosystems (LMEs), and this classification is used as a basis for supporting, through the projects of the Global Environment Facility, a number of coastal conservation and management programmes around the world. In 2007, a group of ecologists looked at both coastal areas and oceanic islands and created a "'nesting'" system for categorizing them. They devised 12 *realms*—such as

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the Arctic, the Southern Ocean, and the Tropical Atlantic—which between them contained 232 *ecoregions*: enclosed or semi-enclosed seas such as the North and Baltic, island groupings like Hawaii and the Galapagos, or contiguous areas that, because of differences in current, temperature, wildlife or some similar variable, are considered sufficiently distinct from each other to merit their own designation.

The ecoregions approach is particularly useful when considering management and conservation of coastal waters: the scale is not so small as to make conservation measures ineffective in the bigger picture, nor so large as to make them unwieldy and unworkable. But they do not, in and of themselves, tell us what lies beneath.

There are, within and across those ecoregions, a plenitude of ecosystems, different habitats and marine life coming together in unique ways, in tidal pools and coral reefs, on sandy beaches and pack ice, in the tropical open ocean and on the dark seabed. In many ways, the easiest way to understand the variety of ocean life and ecology is to start from where the sea meets the land, and work outward and downward.


Nature amazes us, nature challenges us, nature inspires us

flickr/mikebaird

On and Near the Shore

Coastal areas are often among the most dynamic and productive of environments. They are in many ways the definition of living on the edge. Waves crash against rocky cliffs or roll onto sandy shores. Estuaries exhale the last breath of river systems, the frenetic riverine pace yielding to a sprawling mixture of fresh- and saltwater.

A beach or an estuary can appear deceptively calm and uneventful. The gentle lapping of waves on shore can be soothing, the languid vista of mudflats can appear serene. But the gulls that scream overhead, the plovers that pick their way through rock pools, the avocets that stride along estuaries are all signs that beneath the surface there is a battle for survival, a battle that requires constant and rapid adaptation. At low tide on rocky shore or sandy beach, shellfish bury into the sand or close tight to seal in moisture and protect themselves from predators, particularly the shorebirds that explore tidal pools and beaches in search of food. As the tide rolls back in, they emerge, filtering

There are approximately 356,000 kilometres of coastline in the world, almost enough to reach from Earth to the Moon. More than half of that coastline is in Canada, which has almost four times as much as the runner-up, Indonesia. In contrast, tiny Monaco has just four kilometres of coast.[22]

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the water for food but exposing themselves to the attention of fish, which in turn may be plucked out of the water by the birds that now soar above. In estuaries, the subtle but ongoing flow back and forth between freshwater river and saltwater sea could prove fatal to some animals, particularly those that are more specifically adapted to one type of water or the other and which need to protect themselves against absorbing or losing too much salt. Remarkably, some soft-bodied molluscs and worms are able to change the composition of their bodily fluids to match the salinity of the water surrounding them, while fish such as salmon, which spend parts of their lives in both rivers and seas, use their gills to regulate the amount of salt they ingest.

In warm estuarine waters of the tropics, mangrove trees adopt similar strategies that enable them to thrive in brackish waters, their ability to expel excess salt so effective that their leaves may be coated with salt crystals. Hot and humid, otherworldly mangrove forests are a hybrid of terrestrial and marine: above the water, insects colonize and crawl over the trees. Birds nest in the branches, and monkeys swing from them. Even though there is no

Mangrove roots, Everglades National Park

flickr/afagen

soil, the swampy vegetation is sufficiently thick and lush that herbivorous mammals such as deer and antelope thread their way through it and feast on it, while also remaining alert for aquatic predators such as crocodiles and alligators and even, in the Sundarbans of India and Bangladesh, terrestrial carnivores like tigers.

Beneath the water's surface, the thick roots of mangrove trees are covered with filter feeders like oysters, mussels, and anemones. Fiddler crabs dig holes in the mud that males defend fiercely with their oversized right claws, and for good reason: at low tide, the crabs scuttle out of their burrows in search of food, but dry out easily and must return to their homes frequently to "top up" with the pools of water that collect there. Some species of the unusual, semi-aquatic fish called mudskippers also rest in underwater burrows during high tide, while others live higher up the muddy shore or even climb trees to avoid drowning.[23]

The difficulties involved in adapting to the ocean's fringes are perhaps highlighted by the fact that although life in many such intertidal habitats may be abundant, it is not always diverse. There are, for example, only 40 species of mangrove tree in the Indo-Pacific region, in contrast to tropical timberlands which can boast 100 or more species in a single hectare.[24]

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Curious neighbours: Anemones give refuge to clown fish/Mudskipper meets fiddler crab


Sea turtle, Great Barrier Reef, Australia

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Beneath the Surface

Worldwide, there are 72 known species of seagrasses, the only marine plants that produce flowers. Whereas mangroves occupy the boundary between fresh- and saltwater, and ocean and land, seagrasses form submerged beds, or meadows, in the sandy floor in shallow coastal seas. In temperate waters, such meadows may be dominated by one or two species of seagrass, while tropical waters generally boast a greater diversity. Seagrass leaves are frequently long and flat, creating a larger surface area of the leaf with which the plants can photosynthesize, and through which they can absorb nutrients and gases from the seawater. The plants' extensive roots anchor the meadows firmly into the sand, making seagrass meadows safe shelter for invertebrates and fish; and the fact that some plants can grow as much as a centimetre per shoot per day means they are able to withstand the attentions of a variety of herbivorous grazers, from sea urchins to turtles, manatees and dugongs.


Florida manatee (*Trichechus manatus*), USA

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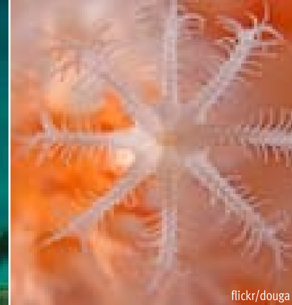

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An infinity of shapes, striking colours and textures, the ocean is home to so many amazing life forms. Here, a tiger shark egg about to hatch, a seahorse nestled in the reeds, a coral polyp of the *Carijoa* species, a neon goby, and bright sea slugs.

To inhabitants of temperate coasts, seaweeds are a familiar sight, forming slippery mats that imperil the balance of anyone crawling over rocks at low tide. When the tide comes in, those same seaweeds sway and undulate in the waves, forming gardens in which fish and invertebrates gather and roam. There are between five and six thousands species of seaweed—marine plants that scientists refer to as macroalgae—in the world, but the largest of them all are kelps, forming not intertidal gardens but subtidal forests. Like their smaller relatives, kelps anchor themselves to rocky substrate, but not in the treacherous zone where sea meets shore. Instead, they grow upwards from the sea floor beyond the low tide, growing by as much as sixty centimetres a day as they race to be close enough to the surface where they can use the sun's light to photosynthesize.[25] Because of the demands of such growth, kelp are found only in cool, nutrient-rich temperate waters, but when conditions are suitable, they can cover vast areas: the coast of California alone has approximately 18,000 hectares of giant kelp growing along its coast.[26] Kelp forests provide a sheltered calm amid the chaos of the pounding surf, and many organisms use the thick blades as a safe shelter for their young from predators or even rough storms. As a result, kelp forests support a greater variety and higher diversity of plants and animals than almost any other ocean community.[27]

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In contrast to kelp forests, coral reefs require clear, shallow waters with an ideal temperature range of between 20 and 30°C. The reefs themselves are structures that have formed over hundreds, thousands or even millions of years by countless tiny organisms called polyps, which produce skeletons of calcium carbonate. Reef-building corals contain symbiotic, microscopic, photosynthesizing algae called zooxanthellae; the polyps provide the algae with carbon dioxide, and the zooxanthellae use sunlight to convert it into oxygen and carbohydrates. The algae are so small that there may be as many as two million of them in each square centimetre of coral tissue, making them by far the most abundant species on reefs, although not the only ones.[28]

Although coral reefs occupy only approximately 0.1 percent of the surface of Earth, one-third of all known marine species live on them, and the total number of reef-dwelling species may number a million or more.[29] Certainly, ecologists believe that they support a greater number of species per unit area than any other marine system, and that they may in fact be the most diverse system on Earth.[30] A study of a 15,000 hectare region in the Philippines documented over 5,000 species of molluscs, most of them tiny and observed just once.[31] As testimony to this abundance and diversity, coral reefs are frequently referred to as “rainforests of the sea”; but such is the riot of life that appears to fill every nook, cranny and crevice that they are in some ways more like brightly coloured, densely populated underwater cities.

The Open Ocean

Blacktip reef shark (*Carcharhinus melanopterus*), Palau

flickr/pacificklaus

The area fringing coastal landmasses is known as the continental shelf; during ice ages, when sea levels were lower, the shelf was the boundary of the continents but now extends offshore underwater by an average of 80 kilometres. That figure, however, varies considerably. In subduction zones, where the crust of the ocean floor, six to seven kilometres thick, developing constantly in the centre of the oceans and drifting away, collides with the much thicker continents, such as off the coast of Chile. Collisions between tectonic plates create topography in which the shelf is virtually non-existent, whereas the largest shelf—the Siberian Shelf in the Arctic Ocean—extends 1,500 kilometres from the shore. Continental shelf waters are relatively shallow, generally between 100 and 200 metres deep. Because they are bathed in sunlight in their upper layers and because their proximity to shore provides them with nutrients from land, they are the most productive waters in the ocean. Coral reefs, seagrasses and kelp forests are all in continental shelf waters, as are the vast majority of the world's fisheries.

Beyond the shelf lies the open ocean, the waters of which—combined with the continental slope that eases downward from the shelf, and the abyssal plain that marks the deep ocean bed far below the surface—comprise the broadest habitat on Earth and the great majority of the planet's livable volume. Peering over the sides of a ship steaming over its surface, it might appear that the open ocean is one big, boundary-free intermixing water, its wildlife swimming back and forth, and from surface to depths, without constraint. Yet even within this vastness, there are delineations.

The upper continental slope, for example, benefits more from nutrients and sediment from land than, for example, the central Pacific Ocean; fisheries for bottom-dwelling groundfish such as halibut have generally concentrated here. The rising, or upwelling, of nutrients from the deep causes the surface waters of the Southern Ocean encircling Antarctica to be more nutrient-rich than those of the tropics; that, combined with the melting of sea ice that contains microscopic algae, feeds springtime blooms of small crustaceans called krill, which in turn sustain a bounty of life including the giant, filter-feeding, great whales. Census of Marine Life researchers found that, although many areas of the open ocean may look equal, to marine animals there are clear differences.

The researchers found, for example, that white sharks congregate in an area off Hawaii that scientists dubbed the "white shark café", and that several species of turtles, seabirds, seals, whales and sharks all congregate at "hotspots" such as in the California Current.[32] Meanwhile, although bluefin, yellowfin, and albacore tunas are all closely related, bluefin can regulate their internal body temperatures while the others cannot. Accordingly, bluefin tunas can swim in both tropical and temperate seas, whereas their kin confine themselves to warmer waters. Additionally, bluefin feed on fish that live in surface waters, while albacore prefer prey that inhabits slightly deeper water.[33]

Indeed, the depth of the ocean is a major factor in determining the life that lives within it, for one main reason. Light from the sun travels 150 million kilometres unencumbered, penetrating through Earth's atmosphere—with some scattering and absorption by clouds, soot and other atmospheric particles—and striking the surface of the ocean. But in even the clearest ocean, that sunlight struggles to reach deeper than 100 metres. Six hundred metres deep, sunlight in the ocean is as bright as starlight on the surface; at 693 metres it is approximately ten-billionth its surface brightness; and by 1,000 metres, the sea is completely dark.[34]

As a consequence, the top 100 metres of the ocean is the zone within which most of the life with which we are instantly familiar—most of the fish, turtles, and marine mammals, as well as the microscopic plankton that forms such an important part of the marine food web—primarily resides. As the sea gets deeper, darker and colder, life seems to all but disappear.

And yet, in waters deeper still, with no sunlight, with atmospheric pressure far greater than a human could withstand, and with water temperatures plunging close to freezing, suddenly and unexpectedly, life once more abounds.

If we did not know it to be from our own ocean, we might easily be convinced that much deep-sea sea life was from another world. While some of it may look vaguely similar in form to life from land or shallower waters, there is an otherworldly aspect to many of the species from the darkest depths. ***Phronima***, a small, transparent crustacean with two pairs of eyes on a hammer-shaped head, is said to have inspired the monster from the movie ***Alien***; like its fictional counterpart, it devours the innards of its prey and lives inside the hollowed-out remains.[35] The giant eyes of the fish ***Winteria***, which inhabits the twilight zone where some sunlight penetrates, look upwards to spot silhouettes of predators and prey and have been described as endowing the fish with the look of an aquatic bush-baby. In the blackest depths, the viperfish has a mouth filled with teeth so long that it cannot even close its mouth, yet it can seize any prey it may stumble across in the gloom. In the absence of sunlight, many deep-sea fish create lights of their own, in the form of bioluminescent symbiotic bacteria that dangle as lures or shine a path ahead like headlights. And marine invertebrates burrow through the silt of the seabed itself, which also contains an unknown number, but possibly very high number, of microbial species.[36]

TOP LEFT: Snailfish of the genus *Paraliparis* David Shale

TOP RIGHT: Deepsea lizardfish (*Bathysaurus ferox*) David Shale

MIDDLE: The Caranchid squid uses transparency to hide from potential predators NOAA/Edie Widder

BOTTOM: Clione is a shell-less snail known as the sea butterfly NOAA/Kevin Raskoff

The Deep Sea

The abyssal plain is not featureless and flat. It undulates, here rising and there falling, and it is these variations in topography that attract the highest diversity of species. Mid-ocean ridges, huge mountain chains forced upward by the actions of tectonic plates, are among the most spectacular geological features on the planet. Hadal trenches, the deepest places on Earth, plunge to as deep as 11,000 metres below the surface of the sea.[37]

Seamounts, underwater mountains that rise 1,000 metres or more from the ocean floor, often have complex surfaces of terraces, pinnacles, ridges, crevices and craters, and their presence diverts and alters the currents that swirl about them; the net effect is to create a variety of living conditions, providing habitat for rich and diverse communities.[38] Deep-sea corals, which unlike their tropical warm-water cousins cannot photosynthesize because of the absence of sunlight, and must instead feed on the detritus of marine organisms, adhere to seamounts' rocky substrate, while some seamounts seem to act as aggregating locations for highly migratory pelagic species such as sharks, which appear to congregate within 30 kilometres of seamount summits.[39] There are believed to be in excess of 100,000 seamounts of 1,000 metres or higher, although only a fraction has been studied.[40]

Red medusa of the *Crossota* species

NOAA/Kevin Raskoff

Perhaps most unique and remarkable of all are the ecosystems that surround hydrothermal vents and cold-water seeps, the discovery of which turned preconceived notions of life on Earth on their head. First seen in 1977, hydrothermal vents occur in volcanically active areas of the seafloor like mid-ocean ridges, where tectonic plates are pushing and pulling above magma hotspots in Earth's crust and where super-heated gases and chemically rich water erupt from the ground at temperatures of up to 400°C. Microbial organisms are able to withstand these extreme temperatures to create energy from the chemical compounds being forced up through the vents—particularly hydrogen sulfide, which is highly toxic to most known organisms—via a process called chemosynthesis. Some of these microbes live symbiotically inside tubeworms, while others form large mats, which attract progressively larger organisms that graze on them. So far, over 500 species that live only at hydrothermal vents have been discovered; it is possible that these communities are the oldest ecosystems on Earth and the place where life began.

Seven years after scientists discovered hydrothermal vents, they began to come across cold seeps, areas on the ocean floor where water, minerals, gases such as methane and compounds such as hydrogen sulfide are expelled from beneath the crust. Unlike vents, those liquids aren't superheated, but like vents, cold seeps support an array of unique, and previously unknown, life.

Gavin Newman/Greenpeace

NOAA/OEP

Unique and fantastic life forms populate the deep seas

NOAA/OEP

NOAA/Steve Ross

Many Areas, One Ocean

The marine iguana (*Amblyrhynchus cristatus*) lives and forages in the sea off the Galápagos Islands

flickr/max_westby

If it is true that the ocean is divided into many different areas, it is also true that there is much to connect them all, and to connect the ocean to the land and the air. Sea turtles hatch on sandy beaches but then spend decades swimming in the open ocean before females return to the same beach from which they came to lay a clutch of eggs and begin the cycle anew. Emperor penguin chicks hatch, and are raised, far inland during the Antarctic midwinter, until eventually making their way to the coasts, resting on ice and swimming in the nearshore waters of the Southern Ocean. Marine iguanas on the Galapagos Islands spend most of their time basking in the sun to warm up and roughly two hours a day swimming in the chilly waters, grazing on seaweed—the only species of lizard that routinely dives into the sea.

Emperor penguin (*Aptenodytes forsteri*), Antarctica

flickr/ianduffy

Pacific bluefin tuna breed in the western Pacific, swim east to the central California coast to spawn and then migrate to the South Pacific, the largest known home range among marine species. Gray whales swim from Alaska to Baja California and back; some humpback whales swim from Antarctica to the waters off Costa Rica, around 8,300 kilometres away, the longest migration of any mammal. But even the humpback must tip its metaphorical cap to the bar-tailed godwit, a shorebird that makes the longest non-stop flight of any bird, almost 12,000 kilometres from the coast of Alaska to New Zealand without once pausing for food.

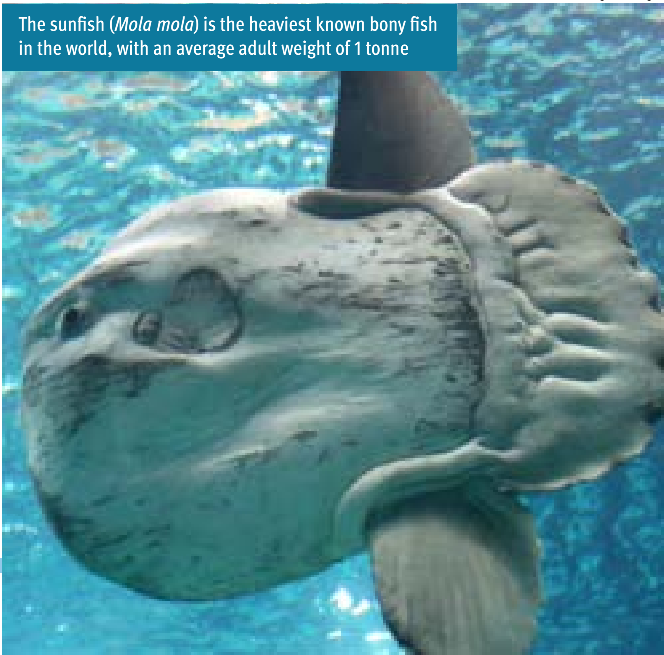
With the apparent exception of hydrothermal vent and cold-seep communities, most of the life that survives in the dark, ocean depths relies for its survival on life near the surface—or, more specifically, the death of that life, which decomposes and falls as detritus known as "marine snow". When whole whale carcasses tumble to the bottom, they are known as "whale falls", and support communities of creatures that have apparently evolved specifically to feed on them and on nothing else. At the same time, as the creatures of the abyssal plain and hadal trenches themselves die, their nutrients also enter the water, and upwelling from currents brings those nutrients in turn to the surface. Multitudes of marine bacteria convert those nutrients into forms that can then be used by the microscopic marine plants known as phytoplankton. Phytoplankton use those nutrients for energy, in combination with carbon dioxide from the atmosphere that they assimilate through photosynthesis. A by-product of that photosynthesis, as with plants on land, is the release of oxygen. In fact, half of all the oxygen in our atmosphere comes from the "breathing" of phytoplankton.[41]

Without life in the ocean, there would be no life anywhere on Earth.

flickr/pacificklaus

Tunicates are marine filter feeders with a saclike morphology

flickr/grantuking



The sunfish (*Mola mola*) is the heaviest known bony fish in the world, with an average adult weight of 1 tonne

A curious diver watches a humphead wrasse (*Cheilinus undulatus*), Great Barrier Reef, Australia

flickr/brewbooks

The Two-Legged Marine Mammal

There is one other marine life form we have yet to mention, but it is one that both has a profound impact on the ocean and has long been profoundly impacted by it. That life form is, of course, *Homo sapiens*.

The tendency is to view humans separately from the natural world, oceans and coasts included, as if we had just been deposited in the middle of them to build cities and generally wreak havoc. But while our species' progenitors likely emerged in and spread outwards from the savannahs of East Africa, human communities have been an integral element of coastal systems in many parts of the world for many thousands of years, and in many places remain so.

The earliest known example of humans turning to the sea for food dates back approximately 164,000 years, when people began using shellfish to supplement their diet at Pinnacle Point in southern Africa.[42] At around the same time, archeological evidence indicates, Neanderthals were collecting and eating molluscs in southern Spain.[43] Recent studies suggest that people may actually have been hunting tuna off the coast of Australia as early as 42,000 years ago.[44] Some researchers believe that the first humans to populate the Americas arrived 13,000 years ago, not by a land bridge between what is now Siberia and Alaska, but by sea, taking advantage along the way of the sea life protected and nurtured by kelp forests that would have at that time been extensively distributed along the Pacific Rim and continental shelf.[45] Others contend that those first inhabitants came not from the west but from the east, in the form of sea mammal and seabird hunters who followed the edge of the Arctic sea ice, which at the time was much farther south than today.[46]

Prehistoric Native American fisheries were taking place along the central California coast at least 7,000 years ago. The ancestors of the Polynesians and Melanesians likely began their vast migration from southeast Asia across the islands and atolls of the Pacific and Oceania about 5,000 years ago. Inhabitants of the Caribbean have been fishing coral reefs in the region

Humans depend on the oceans for food and so many other goods and services

UNEP/Alpha Presse

flickr/noodlepie

for at least 2,000 years. The Greek writer Oppian described fishermen using boats at sea in the first century BCE. By that time, the Romans had established fish processing plants in Spain, Portugal and Morocco. By the year 1000 CE, a culture that was birthed in small fishing villages along the coasts of what are now Kenya, Tanzania and Mozambique had given rise to the large coastal cities of the Swahili.[47] Between 1200 and 1500, people harvested more than five million conches off the coast of modern-day Venezuela. The Ainu culture of Russia and Japan was centered on hunting and fishing, beginning around the year 1200; by that time, the ancestors of the modern-day Inupiat of Alaska and Inuit of Canada and Greenland were hunting bowhead whales.

For many of these coastal peoples and their descendants, the sea was and is rich in meaning and spirituality, religiously significant and central to their very being. The legends and traditions of the Maori of New Zealand feature fishing heavily, with one tale positing that the country was discovered by the great explorer Kupe while hunting a giant octopus.[48] Traditional coastal whalers in Japan maintained Shinto whale shrines and whale temples, where detailed descriptions of the whales and their deaths were maintained. For the Inupiat of Alaska, the hunting of the bowhead whale remains to this day more than a form of acquiring food, but is instead the fundamental act around which every aspect of their society, and indeed the very purpose of their existence, revolves.

flickr/m-i-k-e

flickr/ringai

Today, an estimated 41 percent of the world's population lives within 100 kilometres of the coast, including 21 of the world's 33 megacities.[49] And while those who ply their lives within such enormous conurbations may feel removed from the coast except as a form of recreation, coastal habitats perform a number of vital functions for those communities.

Many coastal environments protect those farther inland from the ravages of the sea. Coral reefs buffer land from waves and storms, and prevent beach erosion. Dune systems on beaches stabilize shorelines from erosion and encroachment. The root systems of seagrass beds stabilize and hold sediments on the sea floor, and the swaying action of the leaves slows the rate at which

iStockphoto/Thinkstock/Luca Coccia

water moves over the seabed, buffering the effect of waves and currents. Mangroves, mudflats and deltas trap sediment, preventing the land behind it from sliding ever-seaward. They also all serve a function in protecting the sea from human activities on land: Mangroves have a great capacity to absorb heavy metals and other toxic substances in effluents, while estuaries, marshes, and lagoons play a key role in maintaining hydrological balance and filtering of pollutants from water.

Those who might not identify themselves as coastal peoples, or who might not consider that they have any particular involvement with, or fealty to, the ocean realm, may be surprised to learn of the role of marine and coastal ecosystems in their everyday lives. For example, sponges from the Mediterranean have been used for painting, cooking, cleaning and even contraception for at least 5,000 years.[50] Substances derived from seaweeds (such as agar and carrageenan) stabilize and thicken creams, sauces, and pastes, are mixed into paint, skin lotion and toothpaste, and used to make paper.

Many marine plants and animals also contain a multitude of substances already being used, or identified as being of potential use, in medicines. Each of the 700 known species of cone snail produces a unique cocktail of 100 to 200 toxins, some of which have already been developed into pain killers: one, which has been on the market since 2004, is more than 100 times more powerful than morphine. Sponges, sea mosses, jellyfish and starfish all deploy toxins to fight off predators and subdue prey, which can also be used in the development of drugs to fight cancer. A 2010 study estimated that there are between 250,000 and 600,000 chemicals in the marine environment, approximately 92 percent of which remained undiscovered; those chemicals, the study's authors estimated, might yield up to 214 new anti-cancer drugs, worth anywhere from US$ 563 billion to US$ 5.69 trillion.[51]

But the one aspect of the ocean that undoubtedly resonates most strongly with people all over the world is the aspect that winds up on many peoples' plates: the fish and shellfish which, caught or farmed, provide a large amount of the world's protein, employment and income.


flickr/avlxyz

According to the United Nations Food and Agriculture Organization (FAO), there are slightly more than four million fishing vessels of all kinds in the world, from industrial trawlers to small boats powered by sails and oars. Between them, all the world's fisheries and aquaculture (fish farming) operations supplied the world with about 142 million tonnes of fish in 2008, of which 115 million tonnes was used as human food (some of the rest would have been used as food for livestock, domestic animals and farmed fish). That averages out to approximately 17 kg for everyone in the world. Fish accounts for 15.7 percent of the world's animal protein; it provides more than 1.5 billion people with almost 20 percent of their average per capita intake of animal protein, and 3 billion people with at least 15 percent of such protein. In 2008, almost 45 million people were directly engaged, full time or, more frequently, part time, in capture fisheries or in aquaculture, at least 12 percent of whom were women. Add the number of people involved in secondary activities such as boat-building, transportation and sales, and that figure rises to 180 million; if we assume that, on average, each of those people has three dependents, then it isn't a stretch to say that 540 million people, eight percent of the population of Earth, depend on fisheries and aquaculture for their income.[52]

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Stephen Schauer

The Human Impact

So vast is the global ocean that one scientist was moved to observe, approximately 50 years ago, that it “may be rash to put any limit on the mischief of which man is capable, but it would seem that those 100 and more million cubic miles of water... is the great matrix that man can hardly sully and cannot appreciably despoil.”

But the ocean, while vast, is not infinite

As scientist Jim Lovelock has observed, “although the weight of the oceans is 250 times that of the atmosphere, it is only one part in 4,000 of the weight of the Earth.” If the Earth were a globe 30 centimetres in diameter, Lovelock noted, the average depth of the ocean would be no more than the thickness of a piece of paper, and even the deepest ocean trench would be a dent of a third of a millimetre.

Accordingly, nor is it immune to human influence

Commercial whaling provided oil for a huge range of uses, from lighting and heating to soap and even nitro-glycerine; at its peak, the riches to be gained from the industry were so immense that European powers would literally do battle over the rights to whaling grounds. But it came at a tremendous cost to the whales themselves: gray whales are no longer found in the Atlantic and are close to disappearing from the western Pacific; in the Atlantic Arctic, bowhead whales number in the hundreds at most. In the Southern Hemisphere, where once there were perhaps 200,000 blue whales, there are now maybe 1,000.

Remarkably, no species of great whale has been exterminated by human predation. The same cannot be said of other species. For example, the great auk, a flightless seabird found on islands in the North Atlantic, was hunted to extinction for its meat, eggs and downy feathers; the last pair, found incubating an egg on an island off Iceland, was killed on 3 July 1844, by Jón Brandsson and Sigurður Ísleifsson, who strangled the adults, and Ketill Ketilsson, who smashed the egg with his boot. Steller's sea cow, a larger relative of dugongs and manatees, was first sighted in 1751; by 1768 it was extinct, a victim of its own "exceedingly savory" meat and of blubber that, when melted, came "pretty close to the oil of sweet almonds." Before it was wiped out, sometime around 1860, the sea mink was never even seen by scientists, who must infer how it looked from bones and teeth. The Caribbean monk seal hung on for longer, but eventually disappeared in the 1950s.


Great hammerhead shark (*Sphyrna mokarran*)

flickr/wendellreed


Hawaiian monk seal (*Monachus schauinslandi*)

flickr/scruffydan

Today, the future for many other species looks equally bleak. The vaquita, a porpoise found only in the Gulf of California, may number as few as 100 individuals. The southern bluefin tuna and elkhorn coral are critically endangered, as are several species of sea turtles. Hammerhead, thresher and white sharks have declined in the Northwest Atlantic by more than 75 percent in 15 years; in the Mediterranean Sea, sharks have declined 99.99 percent from historical abundances in the early nineteenth to mid-twentieth centuries. There may be just 1,110 Hawaiian monk seals remaining, and fewer than half that many of its relative, the Mediterranean monk seal.

The reasons for declines in many numbers of marine species are varied, poorly understood and often the result of a convergence of factors.

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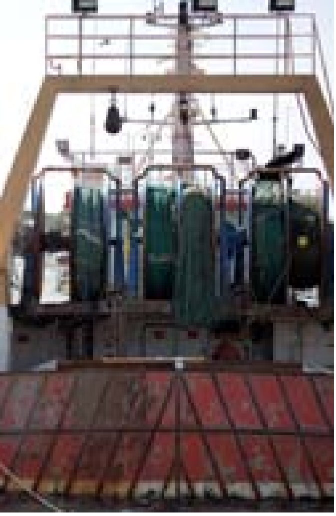
Not Enough Fish in the Sea

In 1883, naturalist Thomas Henry Huxley opined that “probably all the great sea fisheries, are inexhaustible.” If the evidence of the preceding centuries suggested that optimism was questionable, that of the subsequent 120 or so years definitively established it as completely misplaced.

The history of fishing is a history of overfishing. A species of giant clam in the red Sea is believed to have been overfished 125,000 years ago.[53] The Dutch herring fishery collapsed in 1830 and has never really recovered. A century and a half later, in 1992, the cod fishery off Newfoundland collapsed, after dire warnings of impending disaster from scientists, with the loss of 40,000 jobs. Meanwhile, the southern bluefin tuna has been depleted by an estimated 92 percent, and catch quotas for Atlantic bluefin tuna continue to be set at levels higher than those recommended by scientists, leading to concerns for the future of that species.

A 2011 study estimated that 28 to 33 percent of all fish stocks are being over-exploited, and seven to 13 percent have collapsed completely.[54] According to the FAO, 10 species are responsible for 30 percent of the global catch, with anchoveta catches, at 7.4 million tonnes in 2008, by far the largest single catch of all.[55]

Such figures do not include catches for what are known as fishing operations that are illegal, unreported and unregulated (IUU). One study concluded that IUU catches worldwide could total over 12 million tonnes annually, contributing to declines in fish stocks, to the loss of income from legitimate


flickr/infomatique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fisheries interests of up to US$ 10 billion a year, and in some cases to the strengthening of organized crime syndicates that run the illegal fisheries and the marketing of their product.[56]

Commercial fishing has had a particularly devastating effect on large, predatory fish species such as tuna, billfish and sharks. A 2003 study found that, on average, industrial fisheries required no more than 15 years to reduce communities of such fish, and estimated that, overall, 90 percent of predatory fish worldwide have been removed from the ocean. In many cases, these declines have been accompanied by significant decreases in those species' ranges: that is to say, as a result of overfishing, there are areas of the ocean where some species of tuna, billfish and sharks no longer exist.[57] One reason for such a pronounced impact on larger fish is that they are much in demand: bluefin tuna frequently sell in the Tokyo fish market for the equivalent of US$ 100,000; the record, paid in January 2012 by a restaurateur who wanted to jump-start the tuna auction season following the tsunami of 2011, was an astonishing US$ 736,700.[58] Additionally, however, and just as importantly, predatory fish—like predators on land—are generally fewer in number than the species they hunt, produce fewer offspring, and produce those offspring less frequently, while those offspring also take longer to reach maturity and reproduce.

Taking huge amounts of fish from one part of the food web can have cascading impacts throughout the marine ecosystem. For example, declines of 11 species of shark in the Northeast Atlantic led to increases in cownose rays, which prey on scallops and may have precipitated the collapse of the scallop fishery in the region.

The growth in industrial fisheries and subsequent declines in fish stocks began in the Northern Hemisphere in the years following World War II and rapidly followed a pattern of expansion southward, outward and downward: from continental shelf areas of the north to those of the south, then outward into the pelagic zone and downward into the waters of the deep sea. The biggest expansion occurred in the 1980s and 1990s; by the mid-nineties, one-third of the world's ocean and two-thirds of the waters over continental shelves were being heavily exploited or over-exploited, leaving only the relatively unproductive waters of the high seas and the relatively inaccessible waters of the Arctic and Antarctic available for further expansion.[59]

The growth of fisheries into pelagic waters, where marine life is less concentrated than above the continental shelf, required the deployment of fishing gear that was particularly indiscriminate; for example, until they were banned by the United Nations in 1992, high seas driftnets would routinely stretch 50 kilometres, entangling any marine life that would swim into them. Estimates of mortality frequently varied widely but were invariably high: for example, the Japanese pelagic driftnet fishery for salmon in the North Pacific was estimated to catch up to 6,000 Dall's porpoises and 250,000 seabirds a year at its height.[60] (It should also be noted that, although high seas driftnets have officially been banned, their use continues in IUU fisheries worldwide.)

Bycatch—the catching of non-target fish and species such as seabirds, sea turtles and marine mammals—continues to be a considerable problem in fisheries worldwide. A 2009 study argued that, for every 10 tonnes of fish that were intentionally targeted and caught by commercial fisheries worldwide, another four tonnes were caught and discarded.[61] According to the FAO, trawl fisheries for shrimp and for fish in the waters just above the seabed account for half of those discards, and tropical shrimp fisheries alone for more than a quarter.[62] Some fisheries continue to account for very high levels of mortality of marine wildlife: for example, a frequently cited estimate is that 100,000 albatrosses are killed every year when they dive onto the bait that is affixed to the hooks of longline fisheries, become ensnared and drown.

In an attempt to litreally plumb the deepest depths of the ocean, commercial fisheries have turned to bottom trawls, heavily weighted nets that can be as large as 12 metres tall and 60 metres wide, which are dragged along the seabed. Heavy metal doors keep the nets open, and wheels or rollers may ease the net's passage along the ocean floor. As well as being indiscriminate

Consumers have the power to change the industry by making informed and responsible choices

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in the prey they capture, bottom trawls can have devastating impacts on seafloor habitat, as they grind over, knock down and crush everything in their path. Pictures of seabed that initially show vibrant communities of plants and animals reveal, in the aftermath of a bottom trawl's passage through the area, a veritable marine desert. So complete is the destruction wrought by bottom trawling that it is variously referred to as "clearcutting the ocean" and "stripmining the sea." At particular risk are deep-sea corals, which grow on seamounts and which, because of their exceptionally long lives and very slow growth rates (generally in the region of 1 mm a year) cannot easily rebound from damage.

Indeed, as commercial fisheries increasingly turn their attentions to the deep sea, the risk of causing severe damage to populations of fish and other marine life that frequently live on the fringes of existence, is dangerously high, in the cold and dark. For example, Harrison's dogfish, a species endemic to the deep waters off Australia, declined by 99 percent over 20 years from 1976 as a result of trawl fishing and is now regarded as critically endangered. Orange roughy, a large fish that lives near seamounts, grows slowly, can live 100 years and has a very low natural mortality rate, has in recent years been subject to trawl fisheries that have seen catches rise and then plummet off Chile, Namibia, Australia, New Zealand and elsewhere, often after only a decade or so of fishing.[63] As with cold-water corals, the very slow reproduction and growth rates of many deep-sea fishes makes them especially vulnerable to the impacts of fishing—so much so, that it seems likely that for many species, once a stock has been depleted, it will take decades, and potentially centuries, before it will recover.[64]

It is frequently suggested that the solution to all this is to raise fish in "farms" instead of taking them from the wild. Unfortunately, although aquaculture can, under certain circumstances, contribute effectively to the amount of fish available for human consumption, and do so in such a way that does not damage the environment, far too often it compounds the problem that it ostensibly should be helping to solve. More than 33 million tonnes of fish—approximately one-third of the global fish catch—is caught annually for purposes other than human consumption, primarily for reduction into fish oil or fish meal that are used for livestock, and domestic animal feed, but also for feeding to other fish. The amount of fish that has been caught to feed farmed fish such as salmon, catfish, snapper and flounder, as well as species such as tuna that are caught in the wild when young and then fattened in pens, has grown enormously, from under one million tonnes in 1970 to over 13 million tonnes today.[65]

In addition to removing millions more fish from the sea, fisheries for aquaculture, fishmeal and fish oil also take fish that might otherwise find its way into the mouths of hungry people. For example, only 43,000 tonnes—or 0.73 percent of the total Peruvian anchoveta harvest of 5,935,302 tonnes—was destined for direct human consumption in 2006; 99.3 percent of the total anchoveta catch was reduced to fishmeal and fish oil.[66]

Furthermore, of 357,000 tonnes of processed fish products produced in Peru in 2006 for direct human consumption, 329,000 tonnes—over 92 percent—was exported.[67] Nor is that example atypical: although the growth in commercial fisheries is sometimes ascribed to the need to feed a growing world population, approximately 80 percent of internationally traded fish products are imported by the developed world, where population growth and levels of hunger are generally both low.[68] In fact, because the fishing industry has caused fish stocks worldwide to decline and collapse, and because many of those fish have been taken from the waters of less developed nations and consumed by the inhabitants of more developed ones, it has been estimated that, without overfishing, approximately 20 million undernourished people worldwide could have avoided that undernourishment in the year 2000.[69]

A fragile baby ray discovers its surroundings. Crowds, vehicles and construction projects disturb and damage nesting sites of many species.

flickr/smudge9000

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Habitats at Risk

As we have seen, fishing gear can not only remove far too many fish from the sea, it can also damage or compromise the environments species require for their survival—be it the deep seabed, cold-water corals, or tropical coral reefs—in the process. But we are also damaging vital habitats without even setting out to sea.

Sandy beaches, which for many are a comforting sight, a sign of relaxation and vacation, and perhaps the most frequently encountered part of the coast and ocean, are becoming victims of their own popularity. Because many people want to be near beaches, houses, hotels and other buildings are continuing to spring up alongside them; their construction, along with general coastal development, combined with encroachment and inundation by a rising sea, are squeezing beaches into ever-smaller areas. That is causing the decline and loss of habitats vital to shorebirds, sea turtles and a host of other species, a decline that sometimes may actually be exacerbated by well-meaning engineering attempts to arrest beach erosion. Meanwhile, even as they shrink, beaches continue to be magnets for human activity, some of which—for example, the driving of off-road vehicles along the shore—can be hugely detrimental to invertebrates and other beach life.[70]

Other marine and coastal environments are perhaps even more threatened. Shellfish reefs—beds of oysters and other bivalves that are found in tropical and temperate estuaries—may in fact be the most endangered marine habitat of all; as many as 85 percent of them are believed to have been lost around the world. These losses, decades and even centuries in the making, are primarily because of over-exploitation of the shellfish, with additional impacts coming from degraded habitat as a result of coastal development. Disappearance of these reefs affects not only the shellfish themselves but also the broader coastal ecosystem, as the oysters filter seawater, protect the shoreline from erosion, and provide a substrate on which other small animals and plants can live.[71]

Some of the most threatened ecosystems are the ones with the most abundant and diverse life. Since 1980, an area of seagrass meadow the size of a football field has been lost every 30 minutes, meaning that in the time it takes to play a football match, an area equivalent to three fields has been destroyed. Shocking as this figure is, it may be highly conservative, with some suggesting the true rate of loss could be ten times faster.[72] Almost 30 percent of global seagrass extent is believed to have been lost, declines that have put 14 percent of seagrass plant species at elevated risk of extinction. At least as much concern is being expressed, not just for the plants themselves but for the wildlife that seagrass meadows support; indeed, the loss of seagrass meadows worldwide is considered a global crisis, given the number of services that seagrasses provide—including protecting shorelines and providing both habitat for species from turtles to manatees and "nurseries" for a multitude of young fish species.[73] [74] [75] [76]

Similarly, 17 percent of species of mangrove trees are believed to be at elevated risk of extinction, a figure that rises to 40 percent along the Atlantic and Pacific coasts of Central America.[77] Globally, around 35 percent of mangrove forests have disappeared since 1980, with an additional two percent vanishing each year.[78] For coral reefs, the outlook is perhaps yet more bleak: 34 percent of the world's reefs have already been destroyed or are in imminent danger of collapse, with a further 20 percent at risk of loss within 20 to 40 years— figures that do not include the particular risks posed to coral reefs by increased sea temperatures as a result of climate change.[79]

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A Multitude of Factors

Some habitats face specific threats that affect them more than others. In large parts of Southeast Asia, mangrove forests have been cleared and converted to shrimp aquaculture pens. Salt marshes are being drained by the diversion of rivers with dams. Coral reefs may be damaged by the use of poison or dynamite to catch fish. There are, however, also numerous threats that impact on a wide number of habitats, as well as on marine life more generally. Some of the more significant problems include:

Introduced Species

Humans have been responsible for introducing species into marine and coastal environments for millennia. Cats were introduced to islands in the Mediterranean at least 9,000 years ago, and rats have been introduced to 80 percent of the world's islands.[80] [81]As many seabirds and other species have evolved on islands without having had to form defenses against mammalian predators, such introductions can have devastating effects. Indeed, feral cats on islands are responsible for at least 14 percent of global bird, mammal and reptile extinctions, and are the principal threat to almost eight percent of critically endangered birds, mammals and reptiles.[82] On Gough Island in the South Atlantic, the seemingly lowly house mouse is apparently a significant predator on petrels and albatrosses, the mice taking frequent bites of their much larger prey until the birds succumb.[83]

Various aquaculture species have become established in non-native environments as a result of escape or introduction—for example, Chinook salmon has become established in previously salmon-free waters of southern South America, leading to fears that it will out-compete native species.[84] Many species of tropical fish are now found in aquariums worldwide, where they can be introduced into coastal environments after aquarium owners empty their tanks or dispose of live fish. This is the likely source of the Indo-Pacific lionfish invasion of the western Atlantic region; the first recorded instance was off Florida in 1999, and slightly more than a decade later, the species has become established in coastal waters of much of the western North Atlantic and Caribbean, where, in the absence of natural competitors and predators, it apparently grows to a larger size than in its native environment. A study in the Bahamas found that it reduced the number of juvenile indigenous reef fishes reaching adulthood by 79 percent over a five-week period.[85]

But the most pervasive means of transporting non-native species is in ships' ballast water. To maintain stability at sea, ships take on board seawater as ballast when they leave port and discharge it shortly before arriving at their destination. However, that water may contain the larvae of untold species; it is estimated that ships transport between 3,000 and 10,000 species in this way every day.[86]

Nutrient Pollution

The input of nutrients—primarily nitrogen-based—from land is profoundly altering many coastal ecosystems. The principal sources are synthetic nitrogen fertilizer and animal wastes, which are washed from farms into rivers and streams and then carried to coastal waters. In some areas, the burning of fossil fuels by industry and automobiles is the biggest factor, adding nitrogen oxide to the atmosphere that is deposited by rainfall.[87] Just as fertilizer on land stimulates grass growth, so nutrients entering coastal waters can stimulate the growth of toxic and otherwise harmful forms of phytoplankton, which can explode rapidly in number in what are known as harmful algal blooms (HABs).[88]

Green algal bloom make water potentially unsafe

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Although the factors involved are complex—they include not just the total amount of nutrients entering coastal waters, but also the form in which those nutrients occur, and the ratios of nutrients such as nitrogen and phosphorous—the correlation between nutrient pollution and increased HABs is clear.[89] For example, in the waters of Puget Sound in the north-western United States, there is a strong correlation between increased records of paralytic shellfish toxins, which are produced by specific types of dinoflagellate algae, and the growth in the human population in the region over the past four decades. Off the coast of China, harmful blooms of some plankton species have expanded in recent years, now covering tens of square kilometres instead of a square kilometre or two, and lasting weeks and even months instead of days – increases that can be directly tied to increased fertilizer use. Similar blooms, tied to similar causes, are a feature of the Baltic, Aegean, Northern Adriatic and Black Seas, while a five-year-study showed a strong positive relationship between nitrogen-rich agricultural runoff to the Gulf of California and the development, within days, of extensive phytoplankton blooms.[90]

When the algae die they sink to the bottom where they decompose, and the nutrients contained in organic matter are converted into inorganic form

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by bacteria. The decomposition process uses oxygen, thereby reducing the oxygen content in the water. The reduction in oxygen levels can lead to zones of hypoxia—or greatly reduced oxygen content—or even anoxia, when oxygen is entirely absent from the water column. The number of such hypoxic zones has approximately doubled each decade since the 1960s; they have now been reported in more than 500 locations worldwide, totaling approximately a quarter of a million square kilometres of coastal ocean, and are particularly prevalent in such relatively densely populated areas as the Baltic, Black and East China Seas, and the Gulf of Mexico. Some hypoxic zones may be relatively small in size and brief (perhaps only a day) in duration. Others, however, can persist for weeks, months, or even years or centuries, creating seemingly barren stretches of water where, outside of persistent microbes, little life exists.[91 92]

Toxic Pollution

The number of chemicals and chemical compounds synthesized or isolated annually is extraordinarily high and continuing to increase: by 2008, an international chemicals database listed 33 million chemicals and compounds and was adding 4,000 new ones each day.[93] The most dangerous of these are the persistent organic pollutants (POPs), the most famous of which are probably the polychlorinated biphenyls (PCBs) and the pesticide DDT, but there are many others, including compounds used in pharmaceuticals and veterinary drugs, and generated as a by-product of manufacturing, among many others.[94] Many of the more notorious compounds are now subject to national and international legislation to restrict or eliminate their production, but as their description suggests, they remain highly persistent— indeed, PCBs are likely to remain in the environment for between 70 and 110 years; additionally, the sheer rate of introduction of new chemicals means that even as some of the best-known compounds have disappeared, they have frequently been replaced in the environment by others.[95]

For example, alternatives to the anti-fouling agent tributyltin (TBT), which is being phased out, have been found to be more acutely toxic than the chemical they have replaced.[96] Similarly, the replacement compounds for the banned flame retardants PDBEs are now being found in even higher levels in the Arctic than the original chemicals.

It can be difficult to determine the impacts of toxic contaminants, such as heavy metals or chemical compounds, on marine wildlife in definitive terms, but some linkages have been drawn. Experimental studies have shown that exposure to environmentally relevant pesticide concentrations for just four days may be enough to reduce the growth of juvenile Chinook salmon and consequently their size when they enter the ocean; this would be expected to reduce their chances of survival and the overall productivity of affected populations.[97] In California, the toxic contaminants in stormwater runoff and wastewater discharge, a problem throughout coastal environments throughout the world, have reduced the genetic diversity of the bat star by greatly limiting the dispersal of its larvae.[98]

Mercury has long been released into the atmosphere and the ocean as a result of industrial activities; mercury can be highly toxic to wildlife and humans, and can result in a variety of reproductive and behavioural problems. Fish exposed to mercury in laboratory conditions have exhibited loss of coordination, diminished swimming activity, starvation and mortality.[99]

The most famous example of mercury pollution in marine environments came from the towns on and around Minamata Bay in Japan in the 1950s, where residents began experiencing a wide range of symptoms ranging from numbness in the hands and feet, to vision, hearing and speech impairment, and in some cases even insanity, coma and death. The cause was found to be the consumption of shellfish in the bay that had accumulated mercury from water discharged into the bay by a chemical plant.[100]

Mercury, like many artificially created POPs, is "bioaccumulative": it travels up the food chain in ever-greater amounts as it is ingested by progressively larger organisms. By the time it reaches bluefin tuna, for example, mercury can be found in such high levels that consumption of the fish is discouraged for reasons of human health, as well as the fish's conservation.[101]

Plastics and Marine Debris

The development of modern plastics began in the mid-19th century with the synthesis of polystyrene. But their real expansion was in the first half of the 20th century, with the invention of 150 new kinds of plastic polymers. Their growth is such that it has been estimated that over 300 million tonnes are now being used annually worldwide. The reason for their popularity is evident: they are relatively cheap to produce, they are strong and highly durable, and they can be used in a wide variety of ways.[102] However, plastics have become a major source of marine pollution.

For a long time, the impacts of plastics as pollutants was ignored or understated, as in a 1974 observation that "plastics litter is a very small proportion of all litter and causes no harm to the environment except as an eyesore". In fact, as scientist Jose Derraik wrote in 2002, "the literature on marine debris leaves no doubt that plastics make-up most of the marine litter worldwide."[103] This has been a chronic problem for decades: as far back as 1975, the world's fishing fleet alone dumped approximately 135,000 tonnes of plastic fishing

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gear and almost 24,000 tonnes of synthetic packaging material in the ocean, and a 1982 study concluded that merchant ships dumped 639,000 plastic containers each day around the world. While this problem continues, it is far from the only source: a great deal of plastic debris that enters the ocean has been discarded on the beach or on land and transported to the sea by wind, waves, rivers and sewage pipes.

Plastic debris, particularly plastic bags, but also fishing line, plastic pellets and other litter, is frequently ingested by marine wildlife, including sea turtles, seabirds and marine mammals, which sometimes mistake it for potential prey. These can block gastro-intestinal tracts, fill stomachs (causing the animals to think they are full, reducing or eliminating their urge to feed and thus causing starvation) and cause internal damage and bleeding.

Lost and discarded fishing lines and nets can entangle and break corals, be dragged by currents along the seabed, and ensnare fish, marine mammals, sea turtles and seabirds. Such "ghost nets" can continue fishing for years, entangling and drowning hundreds or thousands of animals and fish. Fishing lines and plastic bands, such as those used on six-packs of beer cans, can frequently become entangled around the necks of young seals and sea-lions, which are playful and curious, and like to poke their heads into loops and holes. As the pups age, they grow into the plastic around their necks, which constricts and cuts into the animal's neck, strangling it or severing its arteries. It has been suggested that declines in populations of the Steller sea lion, endangered Hawaiian monk seal and northern fur seal have at least been aggravated by entanglement of young animals in lost or discarded nets and packing bands.[104]

Nor is the impact of plastic pollution limited to visible debris. "Microplastics" —invisible or barely visible fragments that have fractured off debris and been blown or washed into the sea—have been accumulating in the ocean for four decades, even in the waters around Antarctica. Their particular danger is that they not only contain toxic chemical compounds intrinsic to the construction of plastic, but they also attract and accumulate POPs that are free-floating in low concentrations in seawater. Because they are so small, they are eaten by zooplankton such as krill, creating the potential not only for plankton themselves to be severely affected by high levels of contaminants but also providing a pathway by which those contaminants can progress up the food chain.[105]

Noise

The world beneath the waves is a surprisingly noisy place. Numerous species, from whales to shrimps, use sound to communicate, navigate and threaten across distances from centimetres to hundreds of kilometres. Indeed, because the underwater world can be limiting to other senses such as vision, taste and smell, for many marine species sound is the primary means to communicate and learn about their environment.

However, over the past 100 or so years, as the ocean has become more industrialized, it has also become noisier. Explosives, pile-drivers, drilling, dredging, seismic blasts and sonar provide acute blasts of noise that can induce stress and even physical injury in species as diverse as fish, squid and cuttlefish, and marine mammals; naval exercises that have involved the use of certain types of sonar have, on several occasions, been followed soon thereafter by mass strandings of, in particular, beaked whales.[106] Necropsies of beaked whales stranded in the Bahamas in 2000 clearly revealed that the animals had suffered acoustic trauma resulting in hemorrhaging around the brain, in the inner ears and in the acoustic fats (fats located in the head which are involved in sound transmission); dolphins and beaked whales involved in subsequent strandings frequently showed similar injuries.[107]

Of perhaps greatest long-term concern, however, is the ongoing rise in ambient noise, primarily from shipping, and particularly its impact on communications by several species of great whale, whose vocalizations normally travel hundreds of miles underwater. According to Christopher Clark of Cornell University, noise pollution is "doubling every decade in an urbanized marine environment." As a consequence, he says, a blue whale that was born in 1940 would have seen its "acoustic bubble"—the distance over which its vocalizations can travel and the vocalizations of others can be heard—shrink from 1,000 miles to 100 miles.[108] It has also been found that right whales have been forced to increase the volume of their calls, and that the frequency of those calls has also increased, by approximately 30 hertz, in order to evade the cacophony of anthropogenic noise.[109] All of this matters not least because, as Clark expresses it, "if females can no longer hear the singing males through the [acoustic] smog, they lose breeding opportunities and choices."

A Warmer Ocean

Interacting with, and in many cases magnifying the impact of, all these pressures is an even larger and ever-growing issue: the fact that Earth's climate is changing and the global temperature, on average, is increasing.

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This is happening because of the "greenhouse effect" —a consequence of atmospheric gases that trap the heat that rises from the planet's surface and prevent it from escaping. In itself, this is a natural phenomenon—and indeed, an essential one; without it, Earth would be a frigid, lifeless sphere. But since the mid-18th century, the amount of these greenhouse gases in the atmosphere has been increasing as a result of human activities, including deforestation and other land changes, agriculture and especially the burning of fossil fuels such as coal and oil. The most voluminous greenhouse gas by far is carbon dioxide (CO_2), and its level in the atmosphere has been the single biggest factor in determining Earth's temperature over millions of years. At the time of the last Ice Age, CO_2 levels in the atmosphere were approximately 200 parts per million (ppm); by pre-industrial times, they were roughly 285 ppm. By 1958, the first year of an uninterrupted series of measurements from atop the Mauna Loa volcano in Hawaii, the level had risen to 315 ppm, and is now close to 390 ppm. In other words, there is almost twice as much CO_2 in the atmosphere today as there was during the last Ice Age. Atmospheric CO_2 levels are almost certainly the highest they have been for at least 800,000 years and perhaps as much as 15 million years.[110] And they continue to rise: 2010 saw the greatest leap in atmospheric CO_2 levels in recorded human history.[111]

As a result, the mean global atmospheric temperature has increased by approximately 0.75°C since the mid-19th century; the first decade of the 21st century was the warmest on record, supplanting the 1990s, which previously held that distinction.[112] (The ocean has taken up 93 percent of the additional heat generated by the accumulating greenhouse gases in the atmosphere, already sparing humanity from catastrophic climate changes.) In the ocean, global mean sea surface temperature has increased approximately 0.4°C since the 1950s, a change that appears to be affecting the marine environment and the life it contains in a number of ways.[113]

Because warm water is lighter and less dense than cold water, this increase in surface temperature is likely to lead to what scientists refer to as increased stratification, which means that the upper layer of seawater won't sink and mix with the layers below it, thus preventing the flow of nutrients from the surface to deep water and vice-versa. One consequence of this has already been an expansion of nutritionally poor "ocean deserts" in the Atlantic and Pacific by 6.6 million square kilometres, or 15 percent, between 1998 and 2006; another may be declining oxygen concentrations in the upper layers of the ocean.[114 115] Both of these changes are resulting in declines in phytoplankton, the building block of ocean life and provider of half the planet's oxygen, which is declining by an average of about 1 percent per year, transforming the fundamental underpinnings of marine ecosystems.[116]

A warming ocean may also be a sicker one, as it creates conditions that are conducive to the growth and spread of a number of diseases, and the susceptibility of marine organisms to those diseases. (Conversely, however, a subset of pathogens might decline with warming.)[117] For example, the oyster parasite *Perkinsus marinus* spread across a 500 kilometre range of the northeastern United States during pronounced warming in 1990 and 1991, and corals on the Great Barrier Reef showed greater susceptibility to an emerging disease known as "white syndrome".[118] The most significant threat to the future of the endangered black abalone in California is a disease known as withering syndrome, which is enhanced by periods of ocean warming. In addition, mass mortality events affecting a wide range of species appear to be increasing dramatically; temperature increases appear to be the underlying cause in some of these events, including recent die-offs of, particularly, sponges and sea fans that have been plaguing the Mediterranean for the last 15 years.

Brain coral (*Diploria labyrinthiformis*), Bahamas

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Scientists investigate melt ponds in the Arctic to understand how changing conditions affect the ocean's chemistry and biology

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As temperatures change, some species will adjust their range—generally away from the tropics and toward higher latitudes—while the range of other species will expand and still others will contract. Climate change seems likely to completely change the makeup of some ecosystems. For example, the southeastern Australian sea urchin has recently expanded its range into Tasmanian waters, where its grazing of kelp forests has gone unchecked because of the absence of natural predators in the area, causing what are known as "urchin barrens."[119]

Some regions of the ocean are likely to suffer more rapid and dramatic change than others, but none more so than the Arctic. The area occupied by summer sea ice in the Arctic Ocean and surrounding polar seas is decreasing by approximately 12 percent per decade, and the ice that remains is younger and thinner and thus less able to reform fully during the cold Arctic winter.[120] The possible plight of the polar bear, a species that has evolved specifically to live on the sea ice and which could become extinct in much of its range by the end of the 21st century, has been highly publicized; less widely appreciated is that similar fates may await other "ice-obligate" species such as the ringed seal and walrus, or that the disappearance of sea ice is profoundly altering a marine ecosystem that revolves around that ice melting in spring and the subsequent release of algae that become embedded in the ice floes. Whereas phytoplankton would essentially fall to the bottom and become consumed by life on the seabed, which would in turn be eaten by seals and walruses, warmer temperatures prompt more rapid growth of zooplankton that eat the algae before they have a chance to reach the bottom.[121, 122]

Several coastal habitat types are at risk from a changing climate, for a variety of reasons. Warming has been shown to diminish the diversity of salt marsh communities by effectively drying out the plants and the soil in which they grow. Kelp forests are threatened by, among other things, increased temperatures altering the boundaries of the areas in which they can survive, by decreases in nutrient flows, and by increases in predators such as urchins.[123] And mangroves are potentially particularly susceptible to an encroaching sea, a phenomenon that threatens coastal environments worldwide as a consequence of a rise in global sea levels.[124]

As water warms, it expands, and such thermal expansion is the primary reason why, since 1880, sea level has risen by an average of 22 centimetres; increased warming, combined with groundwater extraction, the melting of glaciers and some melting of the massive sheet of ice covering Greenland, is likely to cause sea levels to rise by a metre, or possibly even significantly more, by 2100.[125, 126] Clearly, such a huge increase in sea level imperils huge areas of coast, posing immense challenges for the viability of significant areas of coastal population.

Of particular concern is the effect of climate change on coral reefs. Coral reefs have a relatively narrow temperature band in which they can thrive; once the temperature exceeds the upper limit of that band—specifically, when the sea water temperature exceeds the average summer level of a particular location by about 2°C for more than a few weeks, the corals become stressed and expel the symbiotic zooxanthellae that give them most of their color, a frequently fatal phenomenon known as "coral bleaching." Although small-scale bleaching has long been recorded following localized temperature increases, mass bleaching is a recent phenomenon. One such example occurred in 1998, when elevated sea surface temperatures led to massive bleaching episodes that extended from the western Pacific across the Indian Ocean to east Africa, killing or severely degrading an estimated 16 percent of corals in the region.[127] Another extensive outbreak took place in 2010, with bleaching observed in every ocean and major sea in which coral occurs, from the Persian Gulf to southeast Asia, the Central Pacific to the Caribbean. In the Caribbean, more than 80 percent of corals surveyed by researchers had bleached, and in many places 40 percent or more had died.[128]

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A More Acidic Ocean

Global temperatures would likely have increased still further but for the fact that approximately one-third of humanity's greenhouse gas emissions have been absorbed by the ocean. While that might appear to be good news for the planet's climate, it has additional consequences for the ocean and marine life. As carbon dioxide dissolves in the ocean, it combines with other molecules in a chemical process that results in a decrease in the pH of seawater—that is to say, it makes the ocean more acidic. In pre-industrial times, the average global pH of the ocean was 8.2; today it is 8.1, and while that change may not seem significant, it means that the ocean is 30 percent more acidic than it was 150 years ago.[129] Experiments suggest that as pH declines, the mortality of a number of fish larvae increases, not least because it alters their behaviour to such an extent that they end up swimming directly toward predators rather than avoiding them.[130]

A particular focus of research into ocean acidification has been on animals and plankton that build carbonate shells or exoskeletons, as those shells will start to erode as acidity increases, and the energy required to create them will be that much greater. That could mean an uncertain future for species such as sea slugs, sea snails, crustaceans and shellfish, and even some types of shell-forming plankton, as well as for the species that feed upon them.[131]

Corals—both tropical and deep-water—are likely to be among the principal victims of ocean acidification. In many cases, they will find it more difficult to build or maintain the skeletal structures that are the basis of reefs. And as they decay or break, combined with additional stresses of overfishing, nutrient pollution, introduced species and a warming ocean, so many of the species that depend on the reef will likely also decline, leaving what has long been the most diverse habitat in the sea, and possibly on Earth, a mere shadow of what it recently was.[132]


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Toward a Twenty-First Century Ocean

All the above might lead to the conclusion that the ocean's future is not only depressing, but irreversible. The challenges seem so vast, and the scale of human impacts so great, that one could be forgiven for assuming that they are insurmountable. But although the challenges are indeed considerable, change is possible and achievable.

Remarkably, a review in 2011 found that, despite all the damage inflicted upon marine wildlife and habitats over the past decades and centuries, 10 to 50 percent of those populations and ecosystems have shown some recovery, the figure varying depending on the species concerned and the definition of recovery. The rate of that recovery may be slow, and it may lag continued declines, but it is possible.

For example, sea otters, hunted to near-extirpation in parts of California, Alaska and British Columbia, have rebounded over the past 80 or so years, thanks to a combination of protection from hunting and (in the case of British Columbia) relocation—although in California and Alaska those recoveries have stalled or slightly reversed due to such factors as entanglement in fishing gear, and ecosystem changes leading to increased predation by killer whales. The return of sea otters has also led to a rebound in kelp forests, which in the mammals' absence were being overgrazed by the urchins on which otters feed.[133]

In almost all cases, recovery is aided, simple and obvious as it may sound, by a reduction in or elimination of the principal human threat. For example, northern elephant seals experienced a marked recovery after their hunting was banned, and even some whale populations are showing signs of increasing, despite the devastation wreaked upon them by decades and even centuries of over-hunting. In southern California, a ban on beach gill nets resulted in the slow recovery of severely depleted great white bass and other predatory fish. A ban on beach seine nets contributed to marked increases in fish abundance in Kenya. Reductions in nutrient pollution have resulted in recoveries of some seagrass beds in North America and Europe, and the implementation of strong pollution controls in England's Thames Estuary during the 1960s led to an increase in oxygen levels in the water and the subsequent return of more than 110 fish species.[134]

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The ocean attracts people of all ages

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In many cases, and whenever applicable, a hugely successful factor in recovery can be the use of marine reserves and marine protected areas (MPAs). For example, a comprehensive study found that, on average, coral cover remained stable or increased slightly in areas that were covered by MPAs, while it continued to decline in areas that did not, although because of the slow growth rate of coral, the scale of that increase could be halting.[135] Recovery of coral cover and size distribution after bleaching and hurricane disturbance was significantly enhanced inside a marine reserve in the Bahamas compared to outside, owing to a higher abundance of herbivorous fishes and resulting lower seaweed cover.[136] There is evidence also that protecting species inside a reserve's boundaries can have spillover effects that result in increases in fish outside those boundaries, leading to economic benefits for local fisheries.[137] In Kenya, fishers' catches and income strongly increased after the establishment of closed areas in conjunction with the aforementioned beach seine bans.[138]

The success of reserves and protected areas in coastal waters is greatly enhanced if they are established in cooperation with local people. Indeed, in many instances it is simply essential. For example, in Papua New Guinea, as throughout Melanesia, villagers enjoy customary ownership of inshore habitats, known as customary marine tenure, and recognized as such by the Papua New Guinea government. In 2004, researchers with The Nature

Diver swimming with a whale shark (*Rhincodon typus*)

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Conservancy established a field office near one village and learned from local fishers that nighttime spear fishing and collecting of fish for the live reef fish trade had caused declines in squaretail coralgrouper in several areas. With the community's permission, researchers provided incentives such as money, fuel for boats and food, and employed fishers to determine key fish spawning aggregation areas, while also training them to conduct underwater surveys. Through constant interaction, researchers and fishers were able to work cooperatively to develop a better understanding of the area's marine resources, and the village was able to use that information to develop genuinely community-based management that included bans on spear fishing in key areas.[139]

The only well-enforced no-take reserve in the Gulf of California, which is located in the waters off the village of Cabo Pulmo, Mexico, was established at the instigation of the local community. By 1999, four years after the reserves establishment, there was little sign of change in the overall biomass (or total weight) of the fish in the reserve; 10 years later, however, overall biomass had soared by 463 percent, and that of top predators and carnivores by 11 and four times, respectively. Working together to protect the reserve is binding the community together, and the villagers are deriving economic benefits from the reserve's existence, including in the form of tourism.[140]

Far less area has been set aside as reserves in marine and coastal waters than on land. Whereas approximately 13 percent of the world's terrestrial surface area is protected in reserves, that figure is a little over 1 percent in marine environments. However, progress is being made, particularly with the establishment of large-scale marine reserves: Papahānaumokuākea Marine National Monument in the northwest Hawaiian Islands, established by the US Government in 2006; the Motu Motiro Hiva marine park around the Salas y Gómez Islands, covering the area east of Easter Island and established by the Chilean government in 2010; and the Chagos Marine Reserve, decreed by the UK government in 2010, encompassing a huge area of the Indian Ocean. Other, even larger, reserves are being considered, including the Kermadec Islands, located between New Zealand and Tonga, and home to 11 percent of the world's seabird species; and the Coral Sea, off the northeast coast of Australia, which at almost one million square kilometres would be the largest marine reserve of all.

One clear way forward is to create economic value from protecting marine and coastal environments and wildlife as a viable alternative to exploiting them. For example, a 2009 report found that whale watching generates US$ 2 billion in revenues a year and is growing rapidly in the three remaining whaling nations, where it is generating a constituency for whale protection.[141] Meanwhile, the economic services and products provided by coastal environments—through, for example, fisheries, coastal protection, cultural values and tourism —have been estimated at nearly US$ 26 billion a year. That figure does not include the emerging area of Blue Carbon.

Blue Carbon refers to the fact that salt marshes, seagrasses and mangroves, in particular, each sequester far greater amounts of carbon per square metre than do terrestrial forests: each year one square kilometre of seagrass absorbs approximately the same amount of CO_2 as 50 square kilometres of tropical forests[142]. The goal of the Blue Carbon Initiative, set up by a coalition of non-governmental and intergovernmental partners, is to develop a mechanism by which a value can be assigned to this carbon, and a market established under which countries would be paid to protect them—simultaneously arresting the decline of rapidly disappearing coastal environments and mitigating climate change.

As part of its Jakarta Mandate on marine and coastal biodiversity, the Convention on Biological Diversity (CBD) is committed to a series of

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specific goals, including the development of a global system of marine and coastal protected areas, making fisheries and mariculture sustainable, blocking the pathways of alien species invasions, increasing ecosystem resilience to climate change, and developing, encouraging, enhancing and implementing wide-ranging integrated marine and coastal area management (IMCAM) that includes a broad suite of measures at all levels of society. The latter of these is particularly important, involving comprehensive assessments, setting of objectives, planning and management of marine and coastal areas for all relevant economic and social sectors. It is a participatory process of combining all aspects of the physical, biological and human components of the marine and coastal areas within a holistic management framework. It involves all stakeholders—decision-makers in the public and private sectors; resource owners and users; managers and users; non-governmental organizations and the general public.[143]

That is vital, because incorporating and empowering all sectors—from small coastal communities to political interests—and operating on a variety of levels, including voluntary community participation and legally binding frameworks, will be essential if we are to tackle the immensity and scope of the problems affecting marine and coastal biodiversity.

UNEP/Alpha Presse/Truchet

Such progress will not be easy. At the 10th meeting of the Conference of the Parties (COP) to the Convention on Biological Diversity in Nagoya, Japan, the Parties to the the Convention noted with concern, for example, the "slow progress towards … establishment of marine protected areas", and the fact that, as noted earlier, such protected areas at sea lag far behind those on land. They noted too that addressing the gamut of issues facing marine and coastal biodiversity requires action on multiple levels, from research to national action to international cooperation, and at multiple levels of society, from governments to local and indigenous communities.

But within what could seem an overwhelmingly broad variety of required actions, several areas of priority stand out; at the same meeting in Nagoya, CBD highlighted them in` its Aichi Biodiversity Targets (www.cbd.int/sp/targets). These targets recognize, for example, the importance of "mainstreaming" biodiversity across culture and society through such steps as education and the removal of subsidies that support and promote activities harmful to biodiversity and environments, of simultaneously reducing direct pressures on and enhancing protection of biodiversity, and ensuring that when natural resources are utilized, such use is sustainable.

Strategic Plan for Biodiversity 2011–2020

VISION

The vision of this Strategic Plan is a world of "Living in harmony with nature" where "By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people."

MISSION

The mission of the Strategic Plan is to "take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet's variety of life, and contributing to human well-being, and poverty eradication. To ensure this, pressures on biodiversity are reduced, ecosystems are restored, biological resources are sustainably used and benefits arising out of utilization of genetic resources are shared in a fair and equitable manner; adequate financial resources are provided, capacities are enhanced, biodiversity issues and values mainstreamed, appropriate policies are effectively implemented, and decision-making is based on sound science and the precautionary approach."

Goals and targets particularly relevant to marine biodiversity are provided below.

STRATEGIC GOAL B: Reduce the direct pressures on biodiversity and promote sustainable use

TARGET 6: By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.

TARGET 7: By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity.

TARGET 8: By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.

TARGET 10: By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.

STRATEGIC GOAL C: Improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity

TARGET 11: By 2020, at least 17 per cent of terrestrial and inland water areas, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.

TARGET 12: By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.

STRATEGIC GOAL D: Enhance the benefits to all from biodiversity and ecosystem services

TARGET 14: By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.

www.cbd.int/sp

For marine and coastal areas, there are several specific and relevant targets. For example, by 2020, all fish and invertebrate stocks and aquatic plants should be managed and harvested sustainably, legally and applying ecosystem-based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems, and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits. Within the same timeframe, at least 17 percent of terrestrial and inland water areas, and 10 percent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures. And by 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.

There is no question, particularly given the scale of the threats posed to marine and coastal biodiversity, that such goals are ambitious. But they are necessary, for time is short. Even as we are continuing to learn much about the environments and wildlife that inhabit our seas and coasts, the threats they face are clear, and the solutions are available. All that is required is the will, the will to recognize that marine and coastal biodiversity is worth more alive than dead, the will to recognize that its protection benefits not only the biodiversity itself but the countless millions who rely on it for their cultural, dietary, pharmaceutical or financial needs, and the will to recognize that the longer the delay, the more difficult solutions become to implement. It requires a will on the part of governments to take top-down action when necessary and to work with communities to provide support for grass-roots activities as appropriate. It requires a will by those same governments to stop distributing largesse in the form of subsidies, which distort the market and remove any incentives not to overfish or not to destroy coastal environments. And it requires will on the part of consumers to educate themselves on the energy they use, the food (and particularly the seafood) they eat, the products they buy, the waste they create, and the chemicals they use in their houses and on their lawns.

The time to act is now, if we are to ensure a healthy and sustainable future for the environments that cover three-quarters of the surface of our globe—the environments that make ours a beautiful, blue planet.

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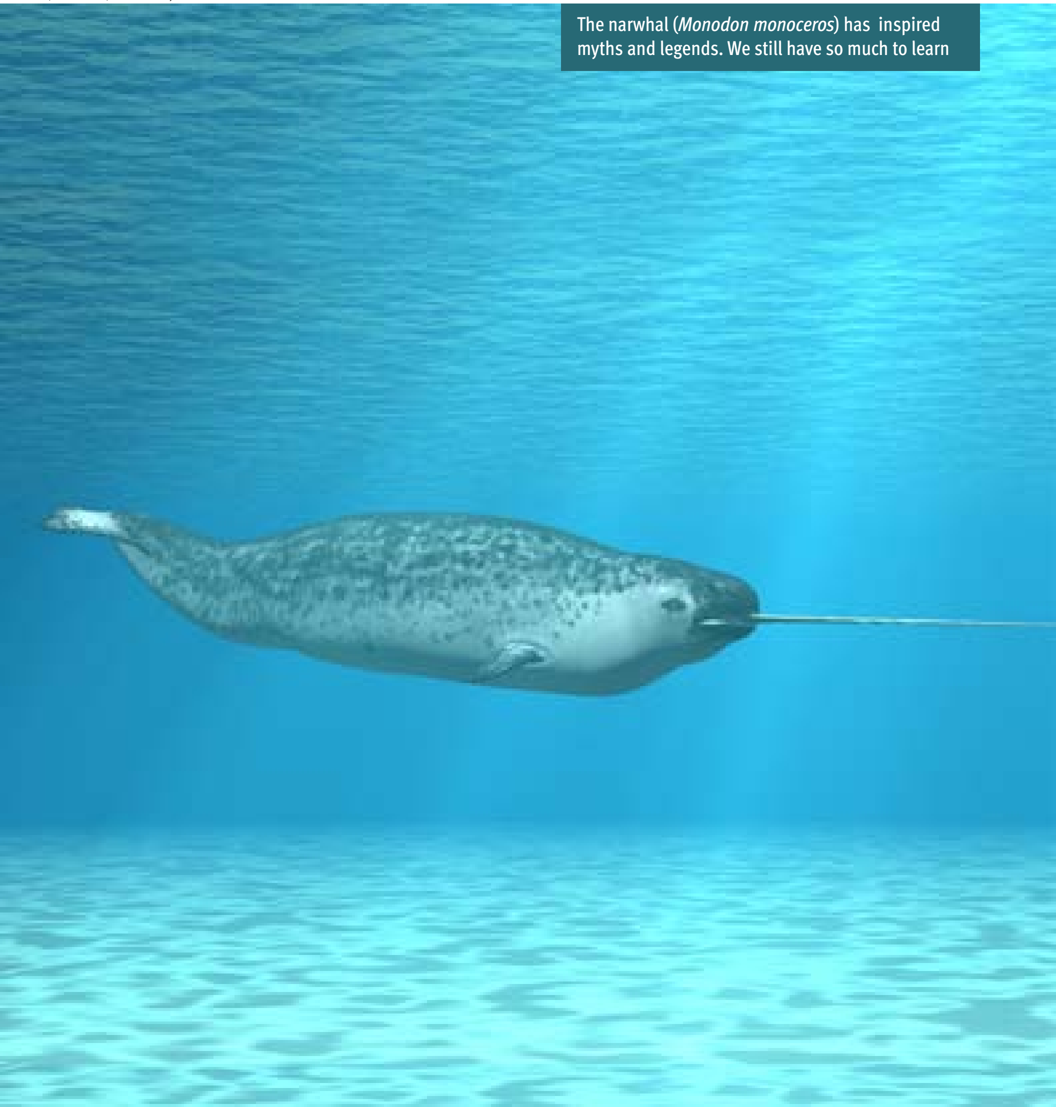

The narwhal (*Monodon monoceros*) has inspired myths and legends. We still have so much to learn

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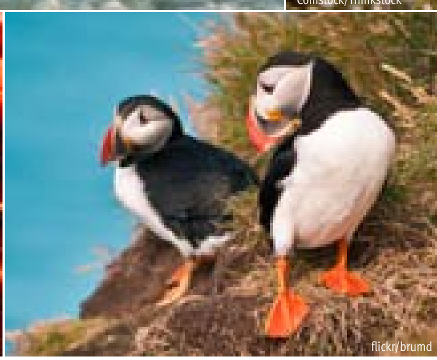
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