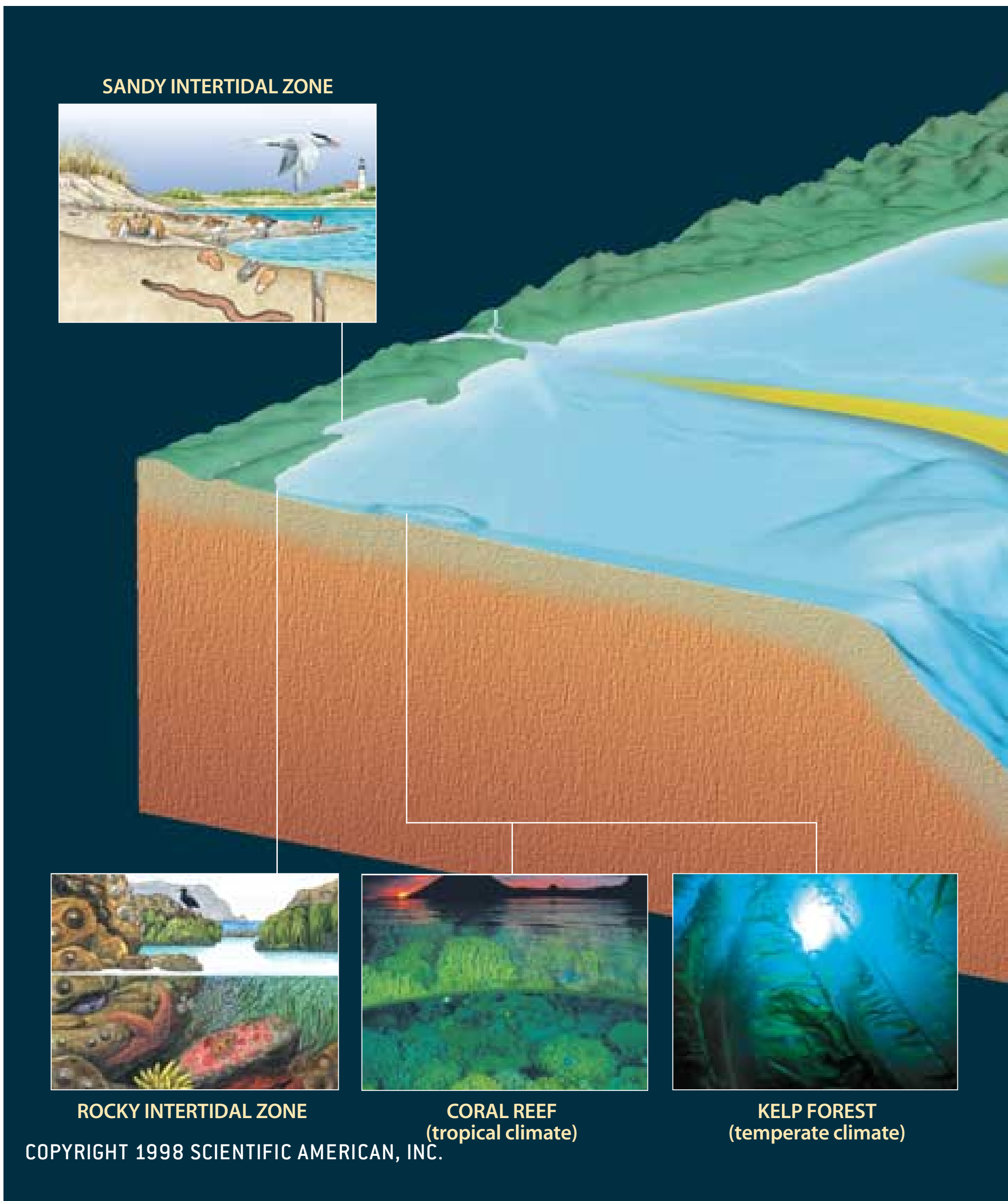
Life in the Ocean

The richest realm on the earth remains largely mysterious

by James W. Nybakken and Steven K. Webster

Earth is misnamed. Even though the planet is largely made up of rock, 71 percent of its surface is covered with ocean. Like the wet film coating a newly washed plum, this water makes up a thin layer compared with the globe as a whole. Yet that watery veneer comprises more than 90 percent of the biosphere by volume: it covers 360 million square kilometers (140 million square miles) and runs, on average, a few kilometers deep. It is in these salty depths that life first emerged four billion years ago, and it is there that life continues to teem today in many strange forms. This blue planet would be better dubbed Oceanus.



OCEAN ECOSYSTEMS exhibit great diversity. Those closest to shore are best known: the intertidal zones, for example, as well as the coral reefs and kelp forests, which occur at the same depth but are mutually exclusive. Parts of the deep sea—including the midwaters and the ocean floor—are only slowly being explored as researchers develop the requisite technology. The movement of nutrients through these ecosystems is fairly well understood (*yellow arrows*): rivers and coastal vegetation supply nutrients to the ocean, just as the upwelling of deep, cold waters provides nutrients to many coastal areas.

The ocean has long been mysterious, its interior largely inaccessible. And although it may not hold the sea monsters that mariners once envisioned, it continues to hold many questions for scientists. Researchers have studied less than 10 percent of the ocean and, because of the difficulty of getting safely to the bottom, have explored no more than 1 percent of the deep ocean floor. Marine biologists know most about the near-shore environments—the coasts, the coral reefs, the kelp forests—and a few other areas that divers can study with ease. But researchers remain ignorant about many aspects of oceanic ecosystems, particularly about life in the midwaters—those between the light-filled upper 100 meters (328 feet) and the near-bottom realm of the deep sea.

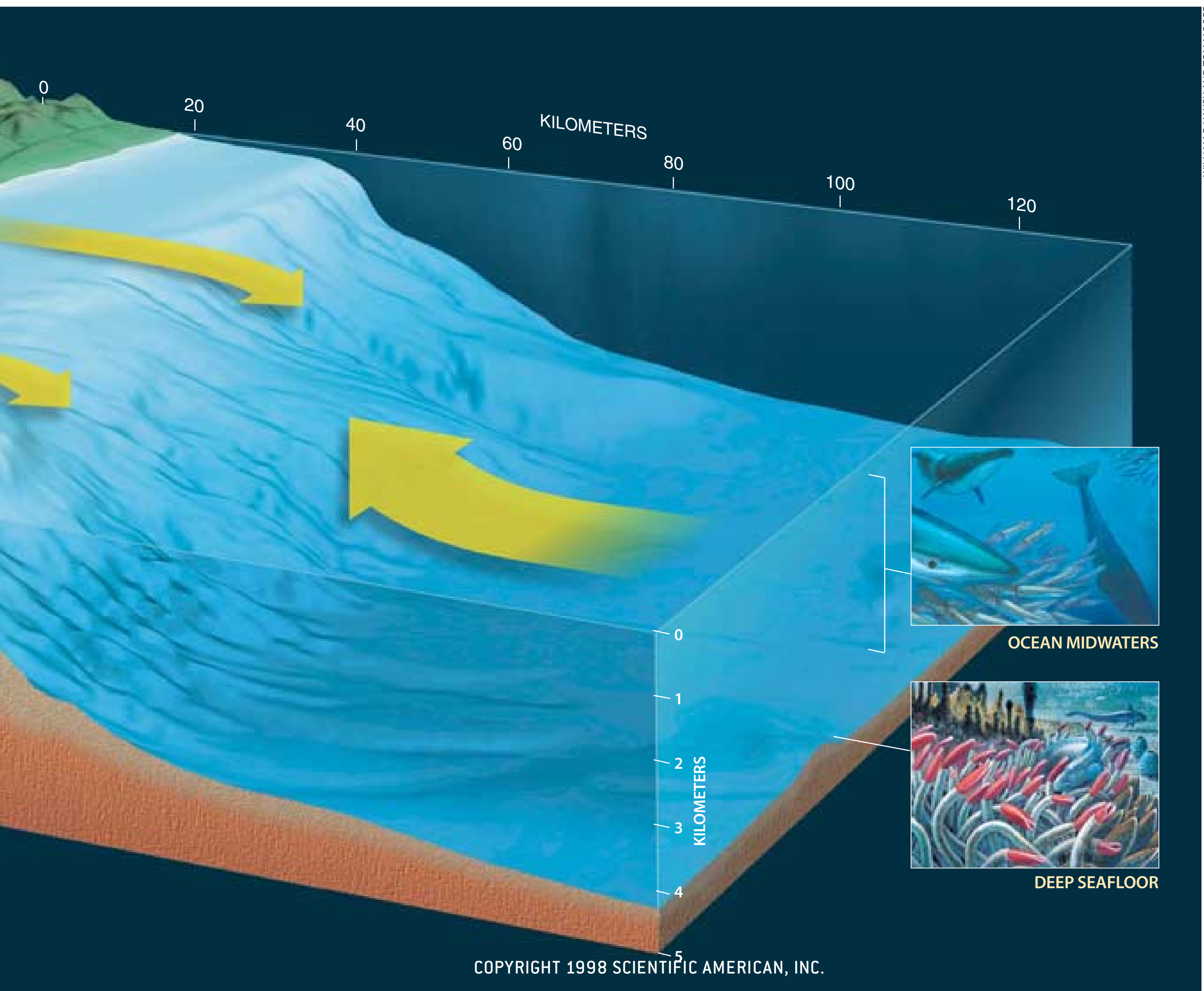
From what investigators do know, it is clear that marine animals display a greater diversity of body types than land animals do. Their scientific description requires more broad categories—that is, more phyla (the second most general taxonomic grouping)—than are needed to categorize their terrestrial cousins. Of the 33 animal phyla, 30 describe residents of the ocean, 15 exclusively so. Only 16 phyla include animals found on land or in freshwater—and of those, only one is exclusively terrestrial. This phenomenon reflects the fact that life evolved in the sea and that few life-forms were able to adapt to the absence of water around their bodies.

Yet at the species level, the reverse appears to be true. One and a half million terrestrial species have been described—mostly insects and vascular plants—but total estimates range from five million to more than 50 million. Of the organisms that live in the ocean, however, only 250,000 species have been identified; total estimates run closer to 400,000 to 450,000. This count may change considerably once scientists get a better grasp of life on the ocean floor: some experts posit that between one million and 10 million benthic species have yet to be described.

Watery Properties

From people's often terrestrially biased perspective, marine organisms can seem odd. Some of these creatures glow in the dark, many are soft and boneless, and most saltwater plants grow fast and die young—unlike trees, which live to a ripe old age. These differences have arisen because of the physical and chemical characteristics of the ocean.

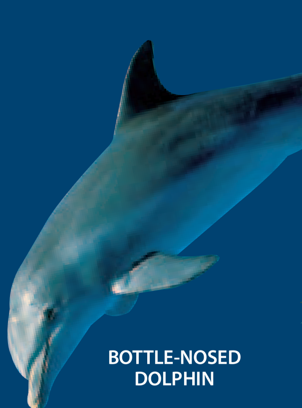
Seawater is about 800 times as dense as air and is much more viscous. Therefore, marine organisms and particles of food can float endlessly through the water—whereas no creatures drift permanently in the air. Because small life-forms and organic particles are constantly wafting about, some sea animals spend their

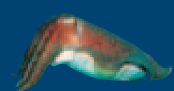


WILLIAM F. HAXBY AND TOM MOORE

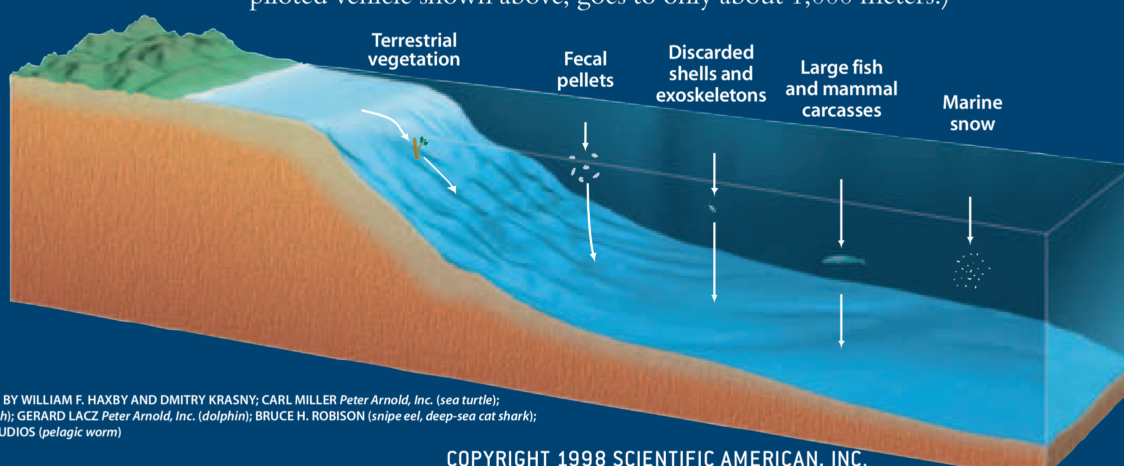
Denizens of the Open Ocean

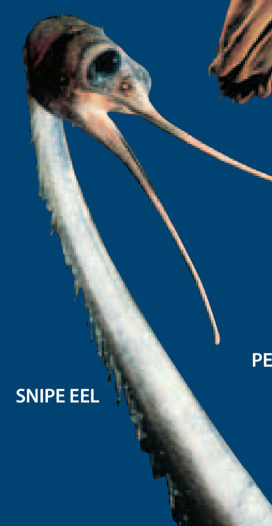

GIANT SQUID
LANTERN FISH
ARISTOSTOMIAS SCINTILLANS
SIPHONOPHORE
SEA PEN
SEA LILY
SEA CUCUMBER
HAKE
DEEP OCEAN FLOOR
GRENADIER
SUBMERSIBLE
DEEP-SEA PRAWN
JELLYFISH
HATCHETFISH





The creatures of the ocean are extremely diverse, reflecting the varied conditions in which they live. Depicted here—and not drawn to scale, so that it is easier to see the organisms clearly—is a small sample of oceanic biodiversity. Many marine organisms stay in the upper waters, feeding on the zooplankton and phytoplankton found there (*at left and top of page*). For their part, residents of the ocean bottom (*at right and directly above*) exist in darkness and under great pressure. Most of the scant food supply in this realm originates in the shallows (*diagram below*). For now at least, the lowest depth that scientists can safely visit is about 6,500 meters (21,300 feet), and so their knowledge of the creatures of the deep seafloor is limited. (*Deep Rover,* the piloted vehicle shown above, goes to only about 1,000 meters.)





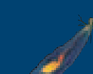


ILLUSTRATION BY ROBERTO OSTI; DIAGRAM BY WILLIAM F. HAXBY AND DMITRY KRASNY; CARL MILLER *Peter Arnold, Inc.* (*sea turtle*); CARL ROESSLER *Bruce Coleman Inc.* (*cuttlefish*); GERARD LACZ *Peter Arnold, Inc.* (*dolphin*); BRUCE H. ROBISON (*snipe eel, deep-sea cat shark*); KIM REISENBICHLER (*vampire squid*); SEA STUDIOS (*pelagic worm*) lives fixed in place, grazing on food in the water around them; on land, only spiders achieve anything like this sedentary lifestyle. The density of water also buoys up organisms, obviating the need for structural supports of cellulose or bone to counteract gravity.

Life underwater has a unique hue as well. Water absorbs light differently than air does. Shorter wavelengths—such as those of the blues and greens—penetrate more deeply than the longer wavelengths of the reds and yellows do. So the view 10 meters below the surface is mostly blue. A few hundred meters deeper there is no sunlight at all and hence no photosynthesis. The midwater and deep-sea communities must depend on the photosynthesizers that reside in the sunlight-filled surface waters. As they sink, these microscopic phytoplankton, zooplankton and decaying particles sustain the fauna of the deep sea.

This rain of plant food is hardly constant, however. Phytoplankton are seasonal and vary by region. Most of the larger species—the ones that turn the ocean green or brown or red when they bloom—thrive in coastal and certain equatorial areas where nutrients are abundant. Much smaller species—called prochlorophytes—are found in tropical and mid-ocean waters. Bottom-dwelling large algae, such as kelp, and seed plants, such as surf grasses, are confined to such a restricted shallow zone around the continents and islands that they contribute little to the overall biological productivity of the ocean, which is relatively modest.

The ocean does not contain much plant life, because concentrations of critical nutrients are lower than they are on land. Phosphorus and nitrogen, for example, are present at only $\frac{1}{10,000}$ of their concentration in fertile soil. As a consequence, the ocean supports only a small fraction of what can be grown on reasonably productive land. One cubic meter of soil may yield 50 kilograms (110 pounds) of dry organic matter a year, but the richest cubic meter of seawater will yield a mere five grams of organic matter in that same interval.

The global distribution of what few nutrients there are depends largely on the temperature stratification of the ocean. In the tropics, surface waters are always quite balmy; in temperate regions, these upper waters warm in the summer and are cold the rest of the year. Below the well-mixed surface layer is a narrow zone—called the thermocline—that separates the warm surface from the colder, and thus heavier, water beneath. (An exception to this common configuration occurs near the poles, where the upper and lower levels of the ocean are equally cold.)

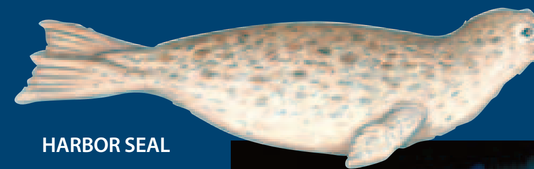
It is this cold, heavy water that is the key to the food chain. Because it receives a constant rain of organic detritus from above, deep, chilly water is richly supplied with nutrients. And because no light reaches it, no photosynthesis takes place there—so few organisms take advantage of this abundant nourishment. In contrast, surface water is often barren of nutrients because the sun-loving photosynthesizers have depleted them.

In the tropics, the separation between the warmth at the surface and the cold at depth is so great that even hurricanes and typhoons cannot completely mix the two. As a result, the waters of the tropics remain bereft of nutrients and of the phytoplankton that depend on them. Lacking these clouds of microscopic life, tropical seas normally stay crystal-clear. In temperate regions, winter storms can churn up the ocean, bringing some of the nutrients to the surface. In certain places such as coasts, where steady winds blow the warm surface waters offshore, deep waters rise to take their place. Such areas of nutrient-rich water support some of the world's largest fisheries.

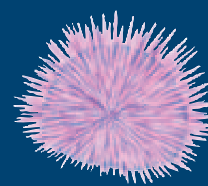
Under Pressure

Temperature and depth also play an important role because these variables control the availability of oxygen. On land, air provides plants and animals with a fairly constant mixture of this life-giving gas: 210 milliliters per liter. In the sea, oxygen enters only at or near the surface. And because most of the water found in the deep ocean originated at the surface in the coldest parts of the world, it sank carrying large amounts of dissolved oxygen. These water masses may spend centuries in the deep sea before they rise again to the surface. But because life is sparse and moves slowly down there, oxygen is rarely depleted. So, strangely, the ocean is often most oxygen depleted at intermediate depths. For example, in certain areas of the Pacific Ocean an "oxygen minimum

The Kelp Forest



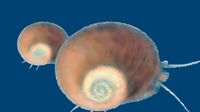
HARBOR SEAL

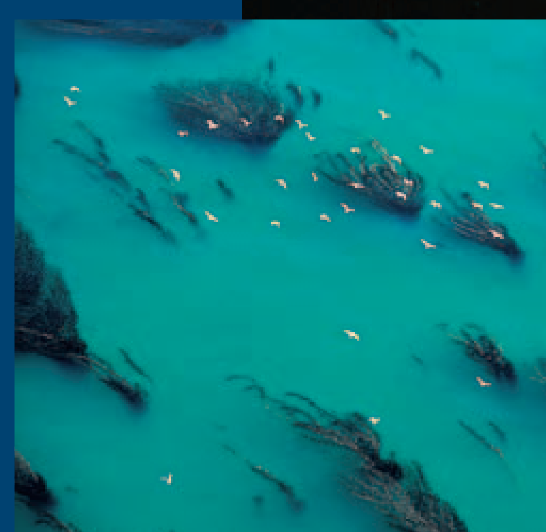


PURPLE SEA URCHIN

ANEMONE EATING A STARFISH

TOP SNAIL





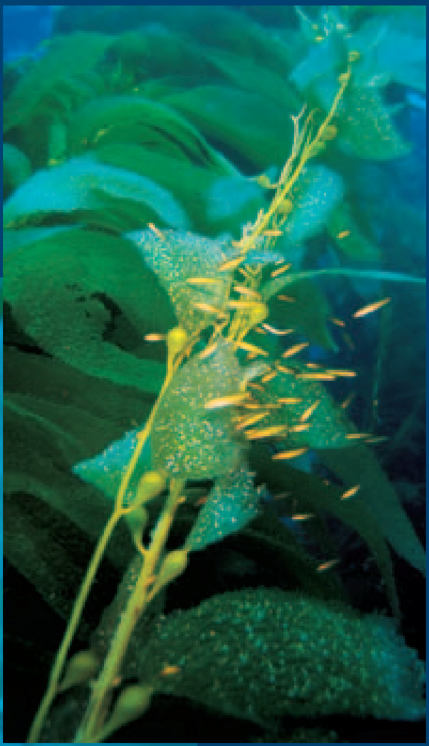
Kelp forests occur in temperate coastal waters, at depths of about 30 meters. Kelp—large, brown algae, which appear green in these underwater pictures—offer fish and invertebrates food as well as shelter from waves and strong currents. As a result, the kelp ecosystem is a rich one: otters, seals, abalone, sea urchins, rockfish, starfish and sea anemones, among many other fauna, thrive in these watery forests. Certain species of kelp can grow as much as half a meter in a single day, reaching great lengths (*lower left inset*).

BLACK ROCKFISH

zone" occurs between 500 and 1,000 meters below the surface. Only a few organisms are adapted to life in this oxygen-poor environment. Most creatures just travel through it quickly on their way to the surface or back down, where the water is richer in oxygen.

Life in that deep realm is under a great burden. Every 10 meters of seawater adds roughly another atmosphere of pressure: at one-kilometer depth the pressure is 100 atmospheres (100 times what people normally experience). In the profoundest ocean trenches, the pressure reaches more than 1,100 atmospheres. Many invertebrates and some fishes can tolerate the trip from one kilometer deep up to the surface—if they do not have gas-filled sacs that expand as they ascend—and can then survive at one atmosphere for years in refrigerated aquariums.

Despite this opportunity to study them in tanks, marine biologists know relatively little about the organisms that live down in those cold, dark regions. Investigators have learned only that the inhabitants of these realms have unusual adaptations that equip them to live in this environment. For this reason, they are some of the most interesting of all oceanic residents.



SENORITA FISH

SEA OTTER

GREEN ABALONE

ILLUSTRATIONS BY PATRICIA J. WYNNE; GREGORY OCHOCK *Photo Researchers, Inc. (kelp forest, senorita fish)*; BARON WOLMAN *Tony Stone Images (aerial view of kelp)*; DOUG WECHSLER *Animals Animals (sea anemone and starfish)*

The Deepest Mystery

Recent studies of the deep sea suggest that although the diversity of species is high, their density is quite low. Food for these organisms arrives in the unending shower of organic particles called marine snow—although sometimes a large carcass, a clump of kelp or a waterlogged tree may settle on the seafloor. Of these sources, though, the marine snow is the most important. As it sinks toward the bottom, microbes, invertebrates and fishes feed on it—and so there is less and less to fall downward. This diminishing supply means there are fewer and fewer consumers at greater depth.

Even more important than the meager, uneven supply of food are the effects of pressure. Deep-sea animals and invertebrates with shells tend to be gelatinous and to have sluggish movements. Their shells are poorly developed because it is difficult to accumulate calcium carbonate under high pressure. If the creatures have skeletons, they are lightweight.

Most deep-sea animals are also small. Many midwater fishes, for instance, are no more than 20 centimeters long. But there are exceptions. Giant squid may reach 20 meters. And the largest comb jellies and siphonophores (relatives of the Portuguese man-of-war) live in the midwater zone, where the absence of strong currents and waves enables these delicate animals to achieve astounding proportions. In fact, the longest animal in the world appears to be a siphonophore of the genus *Praya,* which grows to 40 meters in length and is only as thick as a human thumb. Comb jellies can become the size of basketballs, and the mucus house of the giant tadpole-shaped larvacean *Bathocordaeus charon* may be as large as a Great Dane.

Many of these ghostly creatures glow in their dark abode [see "Light in the Ocean's Midwaters," by Bruce H. Robison; Scientific American, July 1995]. Bioluminescence can be found in 90 percent of the midwater species of fish and invertebrates, and many deep-sea fishes have relatively large eyes, so they can see by this faint light. The luminosity serves a variety of purposes: to identify and recognize species, to lure potential prey, to startle a predator and to warn mates of dangers. At depths of a few hundred meters, where dim light still penetrates, the light enables some organisms to blend in with the brighter surface and render their silhouettes invisible from below. Other advantages probably exist that scientists have not yet discovered.

Although they are able to flash light, midwater fishes are often black in color, and many of the crustaceans are red. Because red light cannot penetrate into deep water, this color provides excellent camouflage. Some large jellyfish and comb jellies tend to be purple or red as well.

The top carnivores, which roam near the surface, seldom have such tints. Tuna, billfish, whales, dolphins, seals, sea lions and even seabirds often move through well-lit surroundings as they travel sometimes thousands of kilometers every year. Their movements to feed—whether they are going from deep water to the surface or moving around the globe—result in the longest migrations of animals on the planet.

Some of these creatures have come to represent sea life for most people, so it remains amazing how little biologists know about their habits. How do sperm whales dive a kilometer deep to locate and capture giant squid? Do the yellowfin tuna of the tropical and the semitropical Pacific intermingle? Or are they separate genetic stocks? Part of the reason for this paucity of knowledge is that whales and open-water fishes are extremely difficult to study because they roam the world. Some whales, for example, migrate every year to feed in areas of cold upwelling near the poles and then travel again to reproduce in warmer latitudes. These creatures are the living oil tankers of the sea: using their blubber as fuel, they undergo vast fluctuations in weight, sometimes losing 30 percent of their body mass during migration.

Right under Our Feet

Not surprisingly, the ocean communities and creatures that researchers know best are those nearest shore: coral reefs, sea-grass beds, kelp forests, coastal mangroves, salt marshes, mudflats and estuaries. These areas are the places people fish, dive, dig for clams, observe shorebirds and, when not paying attention, run boats aground. As a result, these habitats are also the ones people have damaged most severely.

Such environments constitute less than 1 percent of the ocean floor by area, but because they are shallow, well lit and adjacent to landmasses, concentrations of nutrients and biological productivity are relatively high. These coastal areas also link saltwater and freshwater environments. Anadromous fishes, such as salmon, striped bass, shad and sturgeon, reproduce in freshwater rivers and streams, but their offspring may spend years feeding in the ocean before they return to complete the cycle. Catadromous fishes, such as the American and European eels, do the opposite, spending most of their lives in freshwater but going to sea to reproduce.

Perhaps the most familiar near-shore communities of all are those of the intertidal zone, which occupies a meter or two between the high- and low-tide marks. This intertidal stratum is inhabited almost exclusively by marine organisms—although deer, sheep, raccoons, coyotes and bears visit occasionally, as do some insects and a wealth of shorebirds. Organisms living there must be able to endure dryness, bright sunlight and severe shifts in temperature during low tide, as well as the mechanical wear and tear of the waves—which can produce forces equivalent to typhoon winds. It is not surprising, then, to find hard-shelled animals that grip rocks or hide in crevices living there: limpets, periwinkles, barnacles and mussels. Intertidal plants and animals usually occupy distinct horizontal bands that become more densely populated and rich in species at the deeper—and therefore more protected—extreme.

The composition of these littoral communities varies with the shoreline. Sandy shores, for instance, are constantly churned by the waves, so no plants or animals can get a grip for long. Instead most inhabitants are found burrowing underneath the surface. Some tiny animals—called meiofauna—actually live in the interstitial spaces between grains of sand.

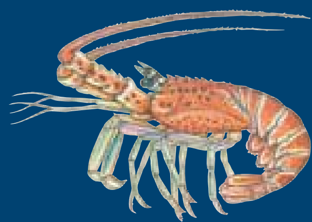
Weather patterns and seasonal variations also influence the makeup of the intertidal zone. Temperate areas have the most developed intertidal communities because summer fogs often protect creatures from direct sunlight. In contrast, rocky shores in the tropics are usually quite bare—consisting of a few diatoms, coralline red algae, cyanobacteria, chitons and nerites (both of which are mollusks).

Farther offshore sit the "rain forests" of the marine world: kelp beds and coral reefs. These ecosystems are mutually exclusive but similar in some ways. Both require abundant sunlight and grow within 30 meters or so of the surface. Both contain dominant species that provide a massive, three-dimensional foundation for the community—giant kelp and reef-building corals, respectively. And both house a vast number of species, although coral reefs surpass kelp forests in this regard.

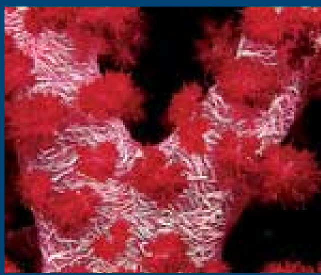
Despite these similarities, their differences are also dramatic. Coral reefs are almost exclusively confined to the tropics, where sea-surface temperatures do not fall below 18 degrees Celsius (about 64 degrees Fahrenheit). Kelp forests do

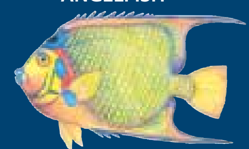
The Coral Reef

Like kelp forests, coral reefs also occur at depths of 30 meters or so but, unlike them, must have warm, tropical water to survive. Corals are colonial animals that live in symbiosis with tiny photosynthetic creatures called zooxanthellae and that produce a hard calcium carbonate skeleton, which forms the essential architecture of the reef. As their varied pigments and the beauty of their inhabitants suggest, coral ecosystems have the highest marine biodiversity recorded so far. They are also highly vulnerable to changes in water temperature and clarity, to infection and to damage by divers, boaters and fishers.


SPINY LOBSTER

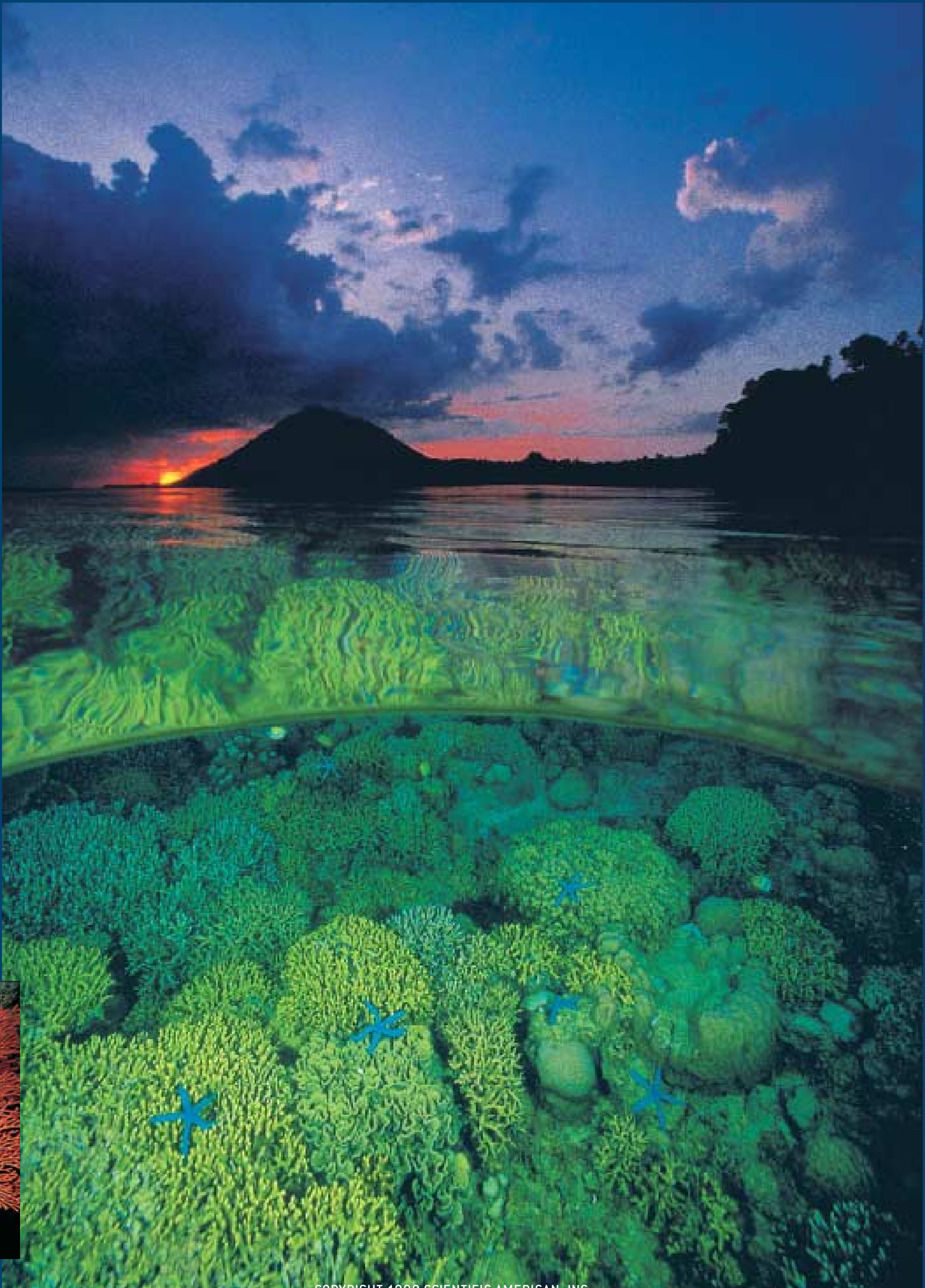

TRUMPET FISH


SOFT CORAL


QUEEN ANGELFISH

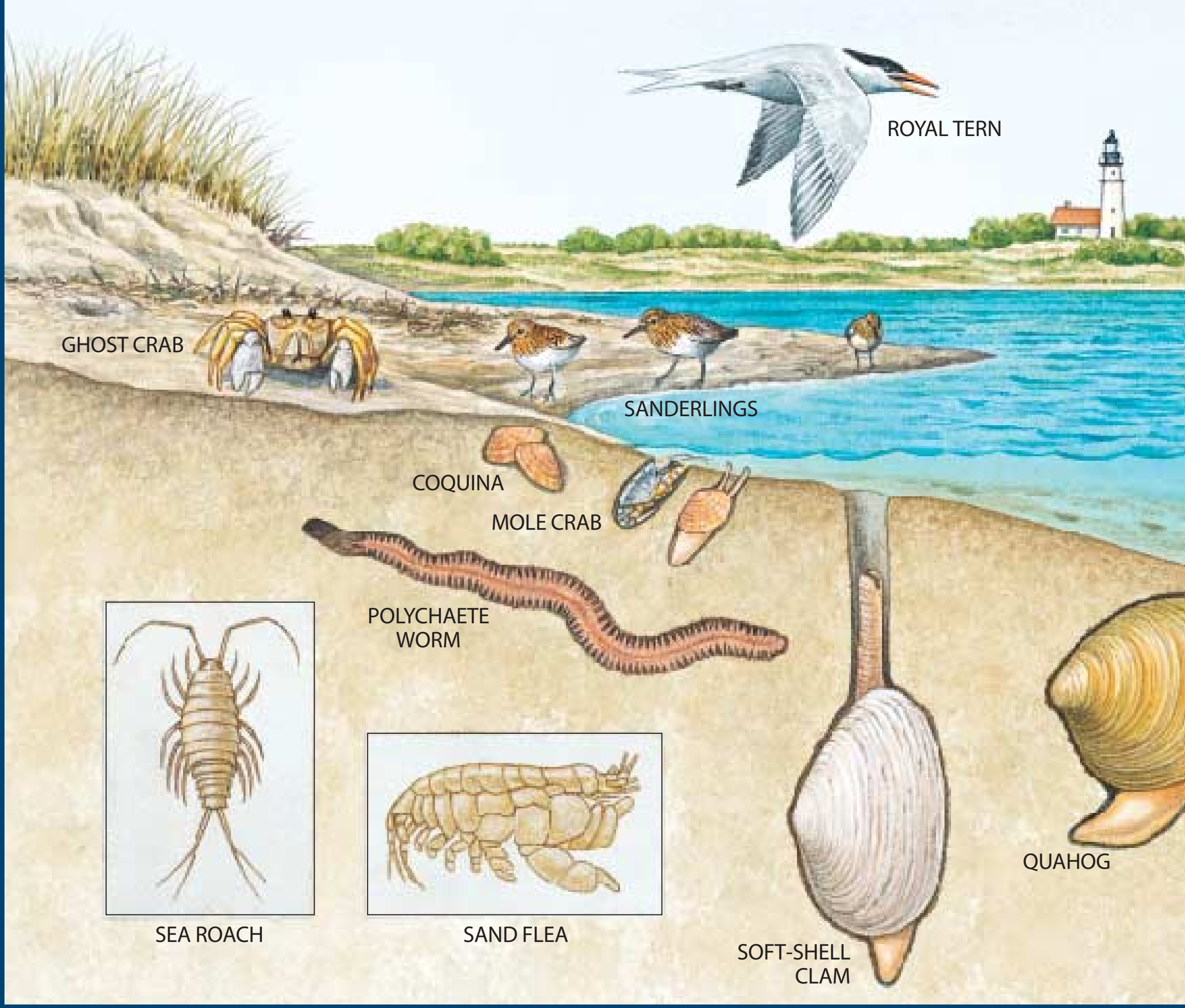

YELLOW SEA FAN

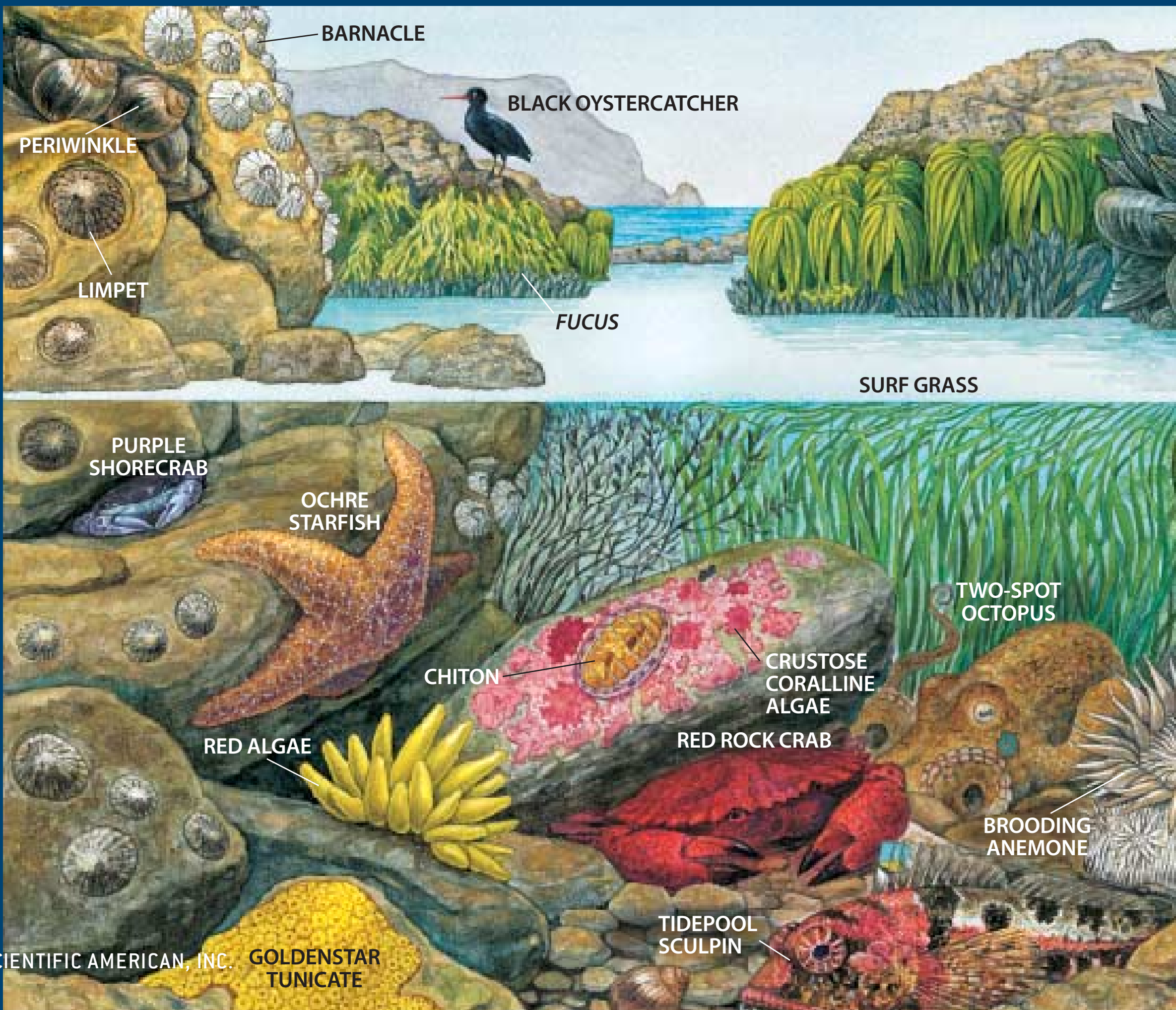
ILLUSTRATIONS BY PATRICIA J. WYNNE; FRED BAVENDAM *Minden Pictures (coral reef, soft coral)*; PETER/STEF LAMBERTI *Tony Stone Images (yellow sea fan)*



The Intertidal Zone

Near-shore habitats are liminal areas, places simultaneously sea and land, where some forms of marine life can be observed with relative ease. (For that reason, these areas often provide people with a window into the adverse effects of coastal development, habitat destruction and estuarine pollution.) Of the many different coastal ecosystems—including mangrove forests, mudflats and salt marshes—two are shown here: a sandy (*top*) and a rocky (*bottom*) intertidal area. The denizens of these places are familiar to most observers.

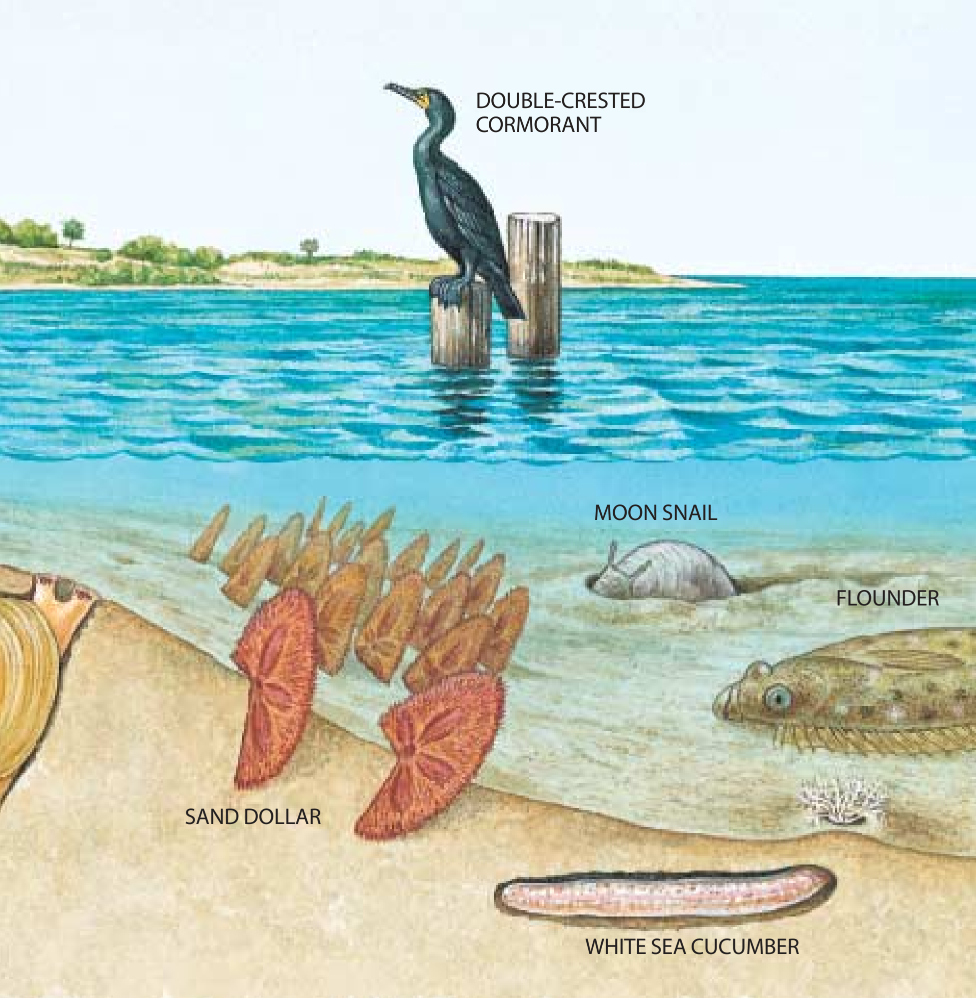


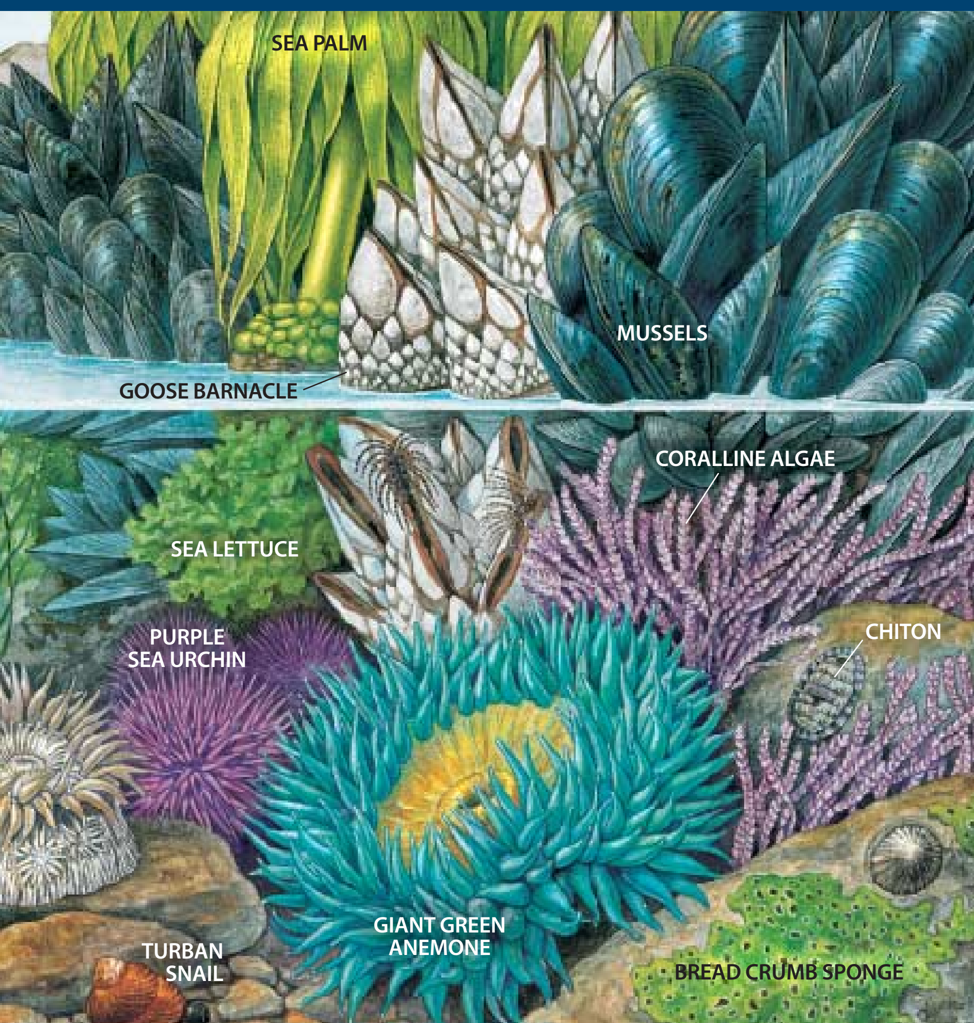


CUP CORAL

CLOWN NUDIBRANCH

STRAWBERRY ANEMONE





ILLUSTRATIONS BY ROBERTO OSTI; PHOTOGRAPHS BY STEVEN K. WEBSTER

poorly in waters this warm; they are best adapted to temperatures between six and 15 degrees C.

Kelp forests are dominated by the large, brown algae for which they are named. The giant kelp (*Macrocystis pyrifera*) can reach 60 meters in length, stretching 30 meters from the seafloor to the surface and then floating to create a thick canopy. Kelp grow very quickly—as much as half a meter a day in some places. Ninety percent of this plant matter is eaten immediately or washes away to the beach or deep sea, where herbivores later consume it.

These aquatic trees soften the waves and currents and provide food and shelter for many kinds of fish and invertebrates. They are principally grazed by sea urchins and abalone, marine invertebrates that are delicacies for humans and sea otters alike. In some years the urchins get the upper hand, eating the local kelp and other algae—and some invertebrates—to near extinction. It may take several years before the giant kelp can reestablish itself. But in areas where sea otters abound, the urchins are usually kept in check. Indeed, before humans began to hunt for sea otters in the 18th and 19th centuries, populations of urchins and abalones probably never reached the sizes that have supported contemporary commercial fisheries.

Human actions have also profoundly affected many coral ecosystems. These communities are built by stony scleractinian corals, by gorgonians (sea whips and sea fans) and, in the Caribbean, by the hydrozoan fire corals. Scleractinian corals are found in all oceans at a variety of depths. But only the tropical, colonial species construct shallow reefs. These species have photosynthetic dinoflagellates (called zooxanthellae) in their gastric tissues—indeed, 80 percent of corals' soft parts can be made of these creatures. The zooxanthellae photosynthesize and provide the corals with food. These symbiotic dinoflagellates also trigger the corals' rapid calcification, which in turn provides the foundation of the reef structure.

Most reef corals need clear water and a depth of no more than 30 meters so that sunlight can reach their zooxanthellae. The reefs usually do not support many fleshy algae, because grazers—such as sea urchins, parrot fish, surgeonfish and damselfish—constantly nibble at any plant growth. In the early 1980s the importance of these grazers was demonstrated when a pathogen killed 99 percent of the long-spined sea urchins in the Caribbean and algae grew unimpeded, crowding out the corals.

A World Ignored

Despite their obvious richness, marine ecosystems have been left out of most discussions about saving biodiversity. Part of the reason is that they are out of sight and, hence, out of mind to many scientists and laypersons alike. Nevertheless, it is important to expand their scope as quickly as possible. Current research suggests that at least 70 percent of the world's fisheries are operating at or beyond sustainable levels [see "The World's Imperiled Fish," by Carl Safina, on page 58], and as human populations grow this pressure will only increase.

The intricate connections between the coastal areas, the surface waters, the midwaters and the deep sea are becoming clearer. If society wants the ocean and its myriad creatures to thrive, people must further study these links—and learn to recognize how human actions can alter, perhaps irrevocably, life in the sea. SA

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Further Reading

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