KELP

The World's Great Forest Under the Sea

by
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It was in the simply marvelous nineteenth century that a shy, retiring hypochondriac—and one of the most profound thinkers of that or any other century—happened to be sailing merrily along thinking about seaweed. Not only did this man eventually pioneer a new way of thinking about the entirety of nature and an organism's place in it; he was the first to note the tremendous richness of kelp forests.

"The number of living creatures of all Orders, whose existence intimately depends on the kelp, is wonderful. A great volume might be written, describing the inhabitants of ones of these beds of seaweed . . . I can only compare these great aquatic forests . . .with the terrestrial ones in the intertropical regions." Charles Darwin wrote that in 1834, off the coast of Chile, where he was in the midst of a six-year stint as naturalist aboard the HMS Beagle. Considering that Darwin was unable to dive into the beds and observe them intimately, this was a remarkably prescient statement.

(In addition to Darwin, the nineteenth century produced a whole bunch of other wonderful things. The potato chip, for instance, was invented and the purple eggplant was developed (they were originally white, you know). On the literary front, the word "frumious" was created by Lewis Carroll and the redoubtable Oscar Wilde penned "The Importance of Being Earnest." Yes, altogether it was a marvelous century.)

KELP: The Basics

What is Kelp?

Kelp is a type of algae. Algae (singular "alga") encompasses a wide variety of relatively primitive aquatic plants. Unlike land plants, they have no roots, no stems, no leaves, no vessels to carry material up and down the plant and

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nothing resembling a flower. Among the many thousands of species, you can find just about every size imaginable, from microscopic ones to 200 foot giants. We usually call any marine algae that are not microscopic “seaweed.” Seaweeds come in a fashionable array of colors and, in fact, that is how they are usually grouped. There are the greens (Chlorophyta, *chloros* = green, *phyton* = plant), reds (Rhodophyta, *rhodon* = rosy red) and browns (Phaeophyta, *phae* = tan, dusky). Just to complicate matters, greens do not always look green, reds do not always look red and browns, you guessed it, don’t always look brown.

The word “kelp” comes from eighteenth century Scotland. Scottish potash makers originally derived potash (which they used in making fertilizer and black explosive powder) from wood ashes. Dwindling supplies of wood led them to use seaweed ashes, which were referred to as “kelp.” Today, “kelp” refers to a specific group of brown algae in the Order Laminariales. They are all large organisms and many are the dominant plants in their habitats. Kelps come in a wide variety of sizes. Some, such as the giant kelp, Macrocystis *pyrifera*, grow to 200 feet or more, while most others rarely attain 10 feet in length.

Because giant kelp is the dominant plant along much of the west coast of Baja California, the United States, and Canada (other closely related species live as far north as Alaska) and because more is known about this algae and its community than any other kelp, we will use this species to exemplify kelp plants and forests worldwide.

Kelp Plant Anatomy

Kelp plants are composed of three basic parts: *holdfast*, *stipe* and *blade*. The kelp holdfast is analogous to, but not the same as, the roots of a land plant. Like a root, the holdfast anchors the kelp plant to the bottom, preventing the plant from being carried away by waves and currents. The various branches of the holdfast wedge themselves into whatever holes, crevices and cracks they find on the bottom. In addition, kelp (and other seaweeds) secretes a sticky substance to help anchor it to the bottom. Unlike a root, a holdfast does not absorb nutrients or water from the environment; it is only an anchoring device. A kelp plant is only as safe as its holdfast is secure. If the holdfast cannot anchor the plant, it will drift away and eventually die. The stipe is like a stem. It is usually smooth (to reduce water friction) and supple (to bend about in the water without breaking). Inside the stipe, elongated cells (*sieve tubes*) conduct the various food products produced by blades at the surface down to the rest of the plant. Some stipes produce gas-filled floats (*pneumatocysts*) that help keep the blades at the water’s surface. Kelp blades are equivalent in form and function to leaves. A blade’s function is to absorb carbon dioxide, water, various nutrients, and sunlight. Then, through photosynthesis, convert them into usable products for the plant’s growth and reproduction. The stipes, floats, and blades of giant kelp and bull

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kelp grow to and across the surface, forming *canopies*, which can cover wide expanses of the near shore continental shelf.

Sex and the Single Kelp Plant

Kelp reproduction was the reason I did not receive an "A" in Introductory Botany. Considering they have no brains, kelp have developed a remarkably complex way of reproducing, one apparently evolved to baffle beginning biology students.

For instance, let's look at giant kelp. Every individual giant kelp plant lives two separate lives: one as a male or female, the other as a neuter. The large, branching plant we see bobbing in the sea is the neuter body, called a *sporophyte*. It has no male or female (sperm or egg-producing) parts. Rather, it produces billions of microscopic spores from special blades near the holdfast. When they are released, the spores swim about and the ones that are not lost at sea, or eaten, settle and attach to a hard spot on the bottom.

After attachment, a spore divides to form a small chain of cells. This tiny plant is the gametophyte and it is either male or female; the males produce sperm, and the females eggs. The females do not release their eggs. Rather, when the eggs are ready to be fertilized, they produce a chemical that drifts about in the current. This is picked up by wandering sperm cells (released by the males) that follow the scent to the eggs and fertilize them. The fertilized egg grows into the sporophyte, which quickly grows and envelops its mother—and the cycle is complete.

Where Do They Live?

Kelps are found in both the Northern and Southern Hemisphere, but always in relatively cool water and always in the ocean. The giant kelp (*Macrocystis* pyrifera), so typical of central and southern California, is actually very abundant in some cool-water pockets along Baja California, as well as in the temperate waters of Argentina, Peru, Chile, Tasmania, and southern New Zealand. Another kelp species, *M. angustifolia*, is found off South Africa and southern Australia. Among other common species are the feather boa kelp (*Egregia menziesii*) and the bull kelp (*Nereocystis luetkeana*). Feather boa kelp lives in very shallow water all along the Pacific Coast. Bull kelp is a quite unusual species, with a long, ropy stipe and a float resembling a sea otter's head. It lives from central California to the Aleutian Islands. If intense storm activity rips out giant kelp, bull kelp may replace it for brief periods. However, after a few years giant kelp usually re-colonizes the reefs.

Most giant kelp lives in waters about 15 feet to 60 feet deep. On very sheltered reefs, such as some in central California, giant kelp survives in almost intertidal waters. By the same token, in a few areas with very clear water (such as Carmel Bay and Catalina Island), you can find isolated kelp plants living in as much as 120 feet of water.

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Why Do They Live There?

Kelp does not live on every stretch of coastline. What factors dictate where it can survive? Actually, there are a number of very important environmental conditions that either encourage, hinder, or prevent kelp growth. Ultimately, it is the *interplay* between a number of environmental factors that determines a kelp plant's fate.

First, and foremost, kelp needs *attachment sites*. Remember, a kelp plant does not have a root structure, so it is not able to fasten itself on or in soft bottoms, as a tree does. In most cases, kelp anchors onto hard surfaces. Most often these are rocky outcroppings, but they may also be boulders, cobblestones, or large shells. Hard rocks, like granite, provide the most lasting, durable anchorage. Kelp plants attached to softer rocks, such as sandstone or shale, are often dislodged because continual water motion pulls on the plants, eventually splintering the rock around the holdfast. Very occasionally, particularly in sheltered areas, kelp plants will attached themselves to small shells or pebbles. If these plants are not dislodged, substantial forests can develop on sandy bottoms. Ultimately, these beds are unstable, and when the occasional massive storm hits (such as the "Hundred Year" storm associated with the 1983 El Niño), these beds are destroyed.

Water motion, particularly waves and swells, has a profound effect on kelp forests. For instance, storm-generated surge can greatly effect a kelp plant's attachment site. In central California, 12-foot-high swells are typical in winter. The force generated by these swells is equivalent to the force produced by a wind speed of 126 miles per hour. Such forces can lift boulders off the substrate and even fracture the bottom. Storm-associated surge is perhaps the most important source of mortality for adult giant kelp plants in California. Whole patches of kelp are torn loose in many storms when one loose individual entangles with other still attached plants, and in turn, rips them loose. Thus, if a kelp plant is attached to solid substrate or if it lives in protected waters, its chances of long-term survival increase.

DRIFTING KELP MATS

What happens to a kelp plant that is torn from the bottom and begins to drift? Well, often the plant is carried on shore, where it quickly disappears as it is converted into food for various sandy beach organisms. But occasionally a plant drifts offshore and, for a short time, begins another existence. As it is carried by wind and currents, the drifting kelp (called a mat) may remain intact for months, drifting hundreds of miles offshore or along the coast. In this pelagic environment, where there is little hard structure, the mat becomes a way station for a number of organisms. Fishes gather around and within a short time, ten or more species may call the kelp plant home. Many of these fishes, such as rockfishes, encounter the mat while drifting as larvae and stay with the structure, where they transform into juveniles. Others, such as adult tunas or dolphinfishes (also called mahimahi or dorados), are attracted to any floating object (kelp, logs, boxes etc.) and may stay with the object for days or

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weeks. The juveniles use the mat for shelter, but it is not always clear why adult tunas or dolphinfishes are attracted to floating debris. While they will often feed on the smaller fishes in the vicinity, they are just as attracted to material which does not harbor other fishes.

Water temperature is a very important factor in a kelp plant's life. Giant kelp, like all organisms, has a ***temperature range,*** within which it can survive. However, even more importantly, it has an ***optimum temperature range,*** within which it grows and reproduces most effectively. Although there is still some uncertainty, the conventional wisdom is that waters less than about 68° F (20° C) are optimal for giant kelp sperm, egg and spore production. When waters reach about 74° F (23° C), reproduction of all sorts is impaired. The adult plants also suffer, as their growth rates decrease and their tissues die.

Probably in response to seasonal changes in water temperature, kelp forests exhibit an annual cycle. In southern California, they grow best during the cold late winter and spring months, then deteriorate with the warm waters of summer and fall. The most obvious sign of this deterioration is the ragged look of the fronds by early autumn. Winters may be hard on kelp plants, particularly in central and northern California, as storms often break the plants off their perches. In El Niño years, when warm water flows north from Baja California, this annual cycle can be disturbed. Large expanses of kelp were damaged and even killed during the extensive El Niño of 1983-84. Various nutrients are closely tied to water temperature and are crucial to a kelp plant's survival. Kelp plants are **photoautotrophic.** The sun provides energy, but kelps require a variety of inorganic and some organic nutrients to manufacture the chemicals necessary for growth and reproduction. Without roots, kelp plants must obtain all their nutrients from the water.

Kelp is the fastest growing plant in the world. Under optimal conditions, a plant can grow two feet per day. Not surprisingly, these plants need lots of nutrients to support all that growth. Nutrients, particularly nitrogen, are most concentrated during periods of **upwelling.** Upwelling occurs when deep, cold, nutrient-rich water comes to the surface to replace surface waters. This most often occurs when they are moved offshore by winds. Most upwelling occurs along coastlines, and only a few coastlines at that. Major upwelling only occurs along the coasts of California, Peru, Chile, West Africa, and a few other scattered spots. In general, kelp grows best during upwellings, which off California are greatest from March to July.

All of these upwelling centers have long coastlines, that run in a north-south direction and they tend to be on the west sides of continents. What is special about these conditions? Some upwelling occurs when winds blow from the land out to sea, pushing surface water with it. But most coastal upwelling is caused by a phenomenon call the Coriolis Effect. As wind blows *parallel* to the coast, it pushes water with it. As this surface water moves along the shore, the Earth is rotating eastward and, in essence, rotates out from underneath

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the water. As far as the Earth is concerned, the water appears to move westward, away from the shore.

Admittedly, this is a bit difficult to grasp, so try this. Let's imagine you could stand in the air, just above the ground in San Francisco. The Earth is rotating eastward, but you are staying in the same place, watching the ground go by. Even though the Earth is rotating eastward, you would appear to be traveling westward. After a while, Hawaii would appear under your feet and a while after that Japan would swing around. About this time, you would probably start regretting having drunk all that coffee a few hours before. If you are a water molecule in the ocean off San Francisco, you would do the same thing. As you are pushed along the coast by the wind, you also move westward, thus offshore. As you move offshore, other water molecules from below you rise and take your place and, *voila*, it's an upwelling. On the other hand, if you are a water molecule on the East Coast, say off New York, you, too, would move westward, but this would take you *toward* the shore.

Water clarity is also very important, since kelp plants need light for photosynthesis. Well-established kelp plants have extensive blades right at the surface, and getting enough light is not a problem. Light levels are primarily important to the very small plants that are just getting started on the bottom. Plankton and suspended debris and sand all decrease the amount of light which descends through the water. In these muddy areas, such as back bays where there is a lot of silt in the water column, there may not be enough light reaching the bottom to allow kelp plants to survive. In addition, the sand or silt in turbid waters may bury or scrape off very small plants (either sporophytes or gametophytes).

To sum up, a kelp plant needs a hard surface for attachment, relatively cool, clear water and *intensive upwelling of nutrients.*

KELP FORESTS

Are Kelp Forests Really Forests?

Broadly speaking, a kelp forest is quite similar to one on land. Each is formed of one or more large plant species (kelp or tree), which dominates the environment. In both forests, there is a tendency for these large plants to shade out smaller plants, preventing them from gaining a foothold. Only when a kelp plant/tree dies or is removed does enough sunlight penetrate to allow extensive new plant growth. In both communities, there are hundreds or thousands of other organisms that live in, on, or associated with these dominant plants. These organisms often tend to partition the kelp plant/tree vertically, specializing in living in one area. For instance, there are many animals that live in kelp holdfasts (such as octopi and brittle stars), but not in the canopy. Similarly, there are many bottom-dwelling organisms that do not dwell in the canopy of trees. The major difference between a kelp forest and a

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terrestrial one is that kelp forests can reach a mature (or "climax") stage very quickly, often within a year or two. In contrast, most trees are relatively slow growing and it often takes decades or centuries for a forest to mature.

Important Associated Organisms

Hundreds of plants, animals, and other organisms live in kelp forests and many occupy specific habitats within the forest. For instance, some species are found only where shelter is available (e.g., in holdfasts or crevices). In fact, a typical holdfast closely resembles a bus station waiting room, with a remarkable assemblage of out-of-the-ordinary organisms. It is not unusual to find thousands of animals in one large holdfast. In fact, it is the sheer quantity of organisms in these holdfasts that often spell a kelp plant's doom. Many of these boarders bore into the holdfasts and unless the plants can produce additional tissue faster than it is destroyed, their hold on the bottom will be weakened and they will eventually be pulled off by storm surge. Kelp forests are also home to many species that live on the open rocks and still others that never visit the bottom, preferring life in the canopy or in midwater. While we can't present them all, here is a sampling of the typical species you might see if you were to visit a kelp bed along the Pacific Coast.

Primarily Benthic (Bottom) Organisms

All kelp forests contain a variety of other seaweeds that compete with giant kelp for living space. Feather boa kelp is usually found inshore of most giant kelp plants (it is adapted to living in shallow, high turbulence, environments). From central California north, bull kelp (*Nereocystis*) is often mixed in with giant kelp. Because bull kelp forms relatively long, slender stipes, without branches, it is less susceptible to waves than giant kelp and often survives in more open, exposed areas. There may also be quite extensive beds of various smaller kelps (e.g. sea palms) whose blades do not reach the surface. Since giant kelp tends to shade the bottom, hindering the growth of these other species, they usually increase their growth when giant kelp plants are ripped out by storms.

Sea urchins are one of the most typical kelp forest animals; they live both in holdfasts and, most often, in adjacent crevices. Three species are most important, the large red sea urchin (*Strongylocentrotus franciscanus*), the smaller purple urchin (*S. purpuratus*) and the smallest white urchin (*Lytechinus anamesus*). These are all remarkable animals. While they feed primarily on drift kelp (kelp broken off from the plant), when that becomes scarce they can live on almost anything else (other algae, carrion, zooplankton, even dissolved nutrients in the water). When drift kelp is scarce and the urchins get hungry, they can cause significant damage to kelp plants and to the entire forest. Hundreds or thousands of hungry urchins emerge from their crevices, forming dense aggregations. These eat virtually anything (particularly attached algae) in their path. In many cases, these urchin swarms create "urchin barren grounds," where no algae survive at all. Urchins keep these reefs algae-free by

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quickly eating any plant which begins to grow on the reef. Moreover, because the urchins can eat virtually anything on the reef that is not nailed down, they can survive on denuded reefs, continually preventing kelp from re-colonizing the rocks. Some of these barren grounds last for years and kelp only returns when occasional massive storms bring in waves which smash the urchin aggregations. Interestingly, when really hungry, the small white urchins will occasionally band together and mob a much larger red urchin, ripping it apart.

Closely related to sea urchins, but looking entirely different, are **sea** cucumbers**.** Holdfasts often contain little ones, while bigger individuals either patrol the areas between plants or hide out in crevices and holes. Sea cucumbers use their tentacles (which extrude from their mouths) to extract food from the water or from the sediment. Often only the tentacles of some species can be seen protruding from their lodging. Common species include the red *Cucumaria miniata*, the small (1 inch long) *Pachythyone rubra* and the large orange-brown *Parastichopus*. In some locations off southern California, as many as 10,000 *Pachythyone* have been found in one square meter. When disturbed (as by a predator), sea cucumbers have the cunning habit of extruding and dumping their sticky respiratory system. This is often poisonous and while the predator is dealing with it, the cucumber shuffles off, later growing another one.

Brittle stars (Class Ophiuroidea) are common in holdfasts and in the rocky crevices of the kelp forest. Brittle stars have been found in densities as high as 300 for every square meter of holdfast. There are various species, but all are highly mobile with long, flexible and very brittle arms. Unlike the closely related sea stars, brittle stars have very few tube feet. Brittle stars feed in a variety of ways. Most kelp bed species are *filter feeders*—they wave their arms about and trap plankton with mucous strands strung between the spines on their arms. *Deposit feeders* collect bits of material from the bottom, roll them into balls and move them toward their mouths (located under the center of the disc). Scavengers browse over carrion or algae with their microscopic teeth. At night you can see hundreds of brittle star arms protruding from various hiding places, scouring the water for prey.

Polychaete worms are extremely abundant at the bottom of the kelp forest, again most commonly in the holdfasts. Most species normally stay hidden, they are rarely seen except when a holdfast is broken or when the substrate is shattered during storm activity. Many are active many-legged critters and prey on other worms or small crustaceans. Polychaetes that are visible generally capture particles from the water with modified head parts or gills that project out from tubes. An aesthetic example is the feather duster worm *Eudistylia polymorpha*, which thrusts its feathery feeding and respiratory plume out of its parchment-like tube. Feather dusters are extremely sensitive to changes in light intensity. If you pass your hand over one, it will snap its plume back into its tube faster than you can follow.

For sheer numbers, crustaceans are the dominant animals at the bottom of kelp forests. Many feed on plankton or other detritus, and in turn they are

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preyed upon by a host of larger animals. Virtually every benthic habitat has its share of barnacles, shrimps, isopods, amphipods, and crabs.

Various molluscs are also typical of kelp forests. **Octopi** (there are several species but primarily *Octopus bimaculatus*) are often found in considerable numbers, particularly deep in the holdfasts. These are reclusive creatures, preferring to spend their days in solitary contemplation, well out of sight. You can often spot an octopus den by the pile of stones the animal has excavated and deposited near the den's entrance. When night comes, octopi leave their split-levels and prowl the substrate, looking primarily for crabs, shrimps, and snails. For all their ungainly appearance, octopi can walk rapidly over sand or rocks. In open water they are truly graceful, quickly propelling themselves backwards, arms streaming away, with jets of water from their siphon tubes. When hunting, octopi lie in wait behind rocks, leap out at their prey and bite them with strong beak-like jaws. Octopi are eaten by a wide variety of animals, particularly moray eels, which are also nocturnal predators.

HOW SMART ARE OCTOPI?

It's hard to test an animal's intelligence, but most people who work with them believe that octopi are pretty smart critters. Almost all octopus researchers have a story or two to back up their opinions. One researcher of my acquaintance had set up six aquariums on a table. The aquariums contained various marine life; in particular one had an octopus and one a number of small crabs. Over time, the researcher noticed that the number of crabs in the aquarium was decreasing, but he could not figure out the reason. The mystery was solved when he came in at night and found the octopus leaving the crab aquarium, crab remains clutched in tentacles and headed for its own. Some time in the past, the octopus had worked its way out of the aquarium, wandered over to the crab tank, and figured out that the cafeteria was open. It was intelligent enough to both enter the new aquarium and always find its way back home.

Nudibranchs are among the most striking of kelp forest animals. These snails without shells come in an outstanding array of colors and shapes, each more aesthetically pleasing than the next. A typical patch of kelp forest might have hot pink nudibranchs, blue with yellow polka dot nudibranchs and purple nudibranchs with orange gills. While nudibranchs are found in many places within a kelp forest (including on the plants themselves, in the holdfasts, and on adjacent rocks and boulders), they are most common near their preferred prey. Nudibranch diets tend to be fairly specific, some species only eat sponges, some only sea anemones, while others only dine on hydroids (small relatives of sea anemones). It's likely that the distinctive colors and patterns of these animals serve as a warning to potential predators. Many species produce noxious chemicals, while others appropriate the stinging cells from their

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hydroid meals. Actually, this latter behavior is pretty amazing. To protect themselves from predators, hydroids produce thousands of stinging cells (*nematocysts*). Normally, when these cells are disturbed, they fire off tiny, poisonous whips, which dissuade the enemy. In some unknown fashion, nudibranchs can eat hydroids without causing the nematocysts to fire. Moreover, the nudibranch gut does not digest the nematocysts, rather these cells are transferred to the *cirrata*, the delicate appendages on many nudibranchs' backs that act as gills. The nematocysts lodge at the cirrata tips, where they are ready for use against potential predators. The combination of chemical and nematocyst defense is a potent one, and nudibranchs have few predators (these are primarily other nudibranchs). I have seen fishes so hungry they would eat lemon drops, inhale nudibranchs, then quickly spit them out.

Among the many fishes living near the bottom in kelp forests, certainly the most obvious is the **garibaldi**, *Hypsypops rubicunda*. This is a small (to about 14 inches long), bright orange species, which is very abundant in southern California and Baja California. Adult garibaldi are extremely territorial, both males and females aggressively guard patches of rock against virtually all comers, particularly other adult garibaldi. These little zealots swim up to intruders and make a sort of popping sound by grinding their throat teeth together. This is enough to drive away fishes three times their size. The only animal a garibaldi does not come after is the harbor seal, which views the fish's antics as before dinner entertainment. When a harbor seal comes about, garibaldi hide in a convenient crevice.

If female garibaldi are zealous about guarding their territories, males (particularly during spawning season), are positively psychotic. Males create nests in their territories by pulling out everything on the rock except red algae. Brown algae, green algae, snails, starfish, everything else is removed. When the red algae nest is ready (in May and June), a male lures a female in, she lays her eggs and the male guards the eggs until they hatch. The only fish that adults will not attack are juvenile garibaldi, which are orange with very distinctive blue spots. A reasonable hypothesis is that the blue spots tell the adults that the fish in front of them is a juvenile, and not sexual competition. The blue spots prevent the adults from attacking the juveniles, a behavior which would result in no next generation.

The **California sheephead**, *Semicossyphus pulcher*, is another common kelp forest dweller off southern California and Baja California; they are occasionally seen in central California, at least as far north as Monterey Bay. Sheephead are very distinctive fish, with heavy jaws, equipped with massive teeth. Females are pink all over, while males have black heads, red mid-bodies and black posteriors. Hard-shelled animals (lobsters, crabs, barnacles, sea urchins) are their favorite meal and their dentition is well-suited for breaking these prey apart. Sheephead have the curious habit of changing sex as they grow older. All sheephead start out life as females and virtually all eventually become males. Most females change sex at about 7 years old, but if there are large males in their habitat, the sex change may be delayed for a while.

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Actually, sex change is the rule in many groups of fishes, particularly in the wrasses (such as the sheephead) and parrot fishes, where most species change from female to male. In many marine basses and groupers, individuals start out as males and become females. Although these fish are polygamous, only the largest males spawn and pass on their genetic material.

Midwater or Canopy Organisms

One of the most common groups of animals living on kelp blades are the bryozoans**;** they are also one of the smallest. Throughout the year, but particularly in summer and fall, you can find a white, very delicate, encrustation on kelp blades and stipes. If you look closely you can see this pattern is formed by a myriad of tiny rectangular structures—these are the bodies of *Membranipora membranacea*. This bryozoan is a *colonial* animal; each rectangle is the body of a single organism, but all the members in the colony originated from a single individual and all are connected by one nervous system. A large colony growing on a kelp blade may have as many as two million members. Bryozoans feed on plankton by extruding a tentacle-bearing fold of tissue and drawing water over the tentacles.

Kelp crabs (*Pugettia*) are a very conspicuous member of the stipe and canopy part of the forest. I have even seen these crabs right on top of the canopy, with their backs exposed to the air. *Pugettia* comes in a becoming variety of colors, ranging from red and orange to blues and browns. Unlike some other crabs, kelp crabs keep their shell extremely clean and smooth, allowing nothing to grow there. These are very active and actually quite graceful animals, capable of traveling up and down kelp plants very quickly.

The **senorita** (*Oxyjulis californica*) is an easily recognized fish in the midwaters of kelp forests from central California southward. These small, cigar-shaped wrasses, equipped with little buck teeth and a black tail spot, have an interesting feeding behavior. Most of the time senoritas pick small planktonic creatures from the water. However, once in a while they get the urge for something different and begin to pick parasites or dead tissue from the sides of other fishes. This *cleaning behavior* is very common in tropical wrasses, but relatively rare in kelp forest fishes. For the cleanee, the major benefit is the reduction of infections around sores or wounds, as the cleaner picks off diseased tissue. The benefit to the cleaner is a cheap meal. In contrast to their tropical relatives, senorita are only part-time cleaners; they will clean for just a few minutes at a time. When they do get the urge, tens or even hundreds of fish come around for the chance to be cleaned. Often it is impossible to see the senorita, as it is completely surrounded by eager supplicants.

Many marine mammals inhabit kelp forests, at least part time. Sea lions, harbor seals, even gray whales often swim into the forests, to feed or rest. However, the **sea otter** (*Enhydra lutris*) utilizes this habitat to a greater extent than any other mammal. Sea otters were once very plentiful from Japan to Alaska and as far south as Baja California. Hunted for their remarkable fur

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(the thickest of any animal in the world, up to one million hairs per square inch), they were driven close to extinction by Russian, Aleut, and American hunters. In California, intense hunting pressure started in 1786 and in less than 100 years nearly 200,000 otters had been killed. Before the start of the sea otter fur trade, the California populations was estimated at about 16,000. Today, there are between 2,000 and 2,500 otters in California, most living between Santa Cruz County and Pt. Conception. Off Alaska, the population is considerably larger, numbering about 200,000 animals.

All marine mammals, including sea otters, are descended from land mammals that returned to the ocean. Sea otters are related to the river otter, weasel, and skunk of the family Mustelidae. The sea otters' ancestors began their aquatic lifestyle much later (perhaps 15 million to 20 million years ago) than the ancestors of the whales (50 million to 60 million years ago), seals, sea lions, or sea cows. Therefore, this species is not as completely adapted to the marine environment. For example, sea otters have not evolved the thick layers of blubber that insulate other marine mammals. Instead their thick fur traps warm air, keeping cold water away from the skin.

In California, sea otters spend a considerable part of their lives in the kelp forest. Not only does the forest provide much of their food, it is also a relatively safe place to sleep and raise young. The otters' major predators, white sharks and orcas, rarely come into the forests. Otters even go so far as to wrap themselves in kelp at night when they sleep. Kelp forests serve as nursery grounds for females with young pups. They wrap their young when foraging, to prevent the kids from floating away.

It's easy to get emotionally attached to sea otters. They are furry and cuddly and have all those really cute little mannerisms. But it would be a disservice to let our feelings get in the way of reality. Sea otters cause profound changes in the populations of many near-shore animals and we should view this with a clear eye. Sea otters have a high metabolic rate and must consume 25% of its body weight daily to meet its energy needs. A 60 lb. animal must eat about 15 lbs. of food (muscle tissue, no shells included) per day. That is a lot of food. Since most of an otter's diet is composed of large, slow-moving invertebrates (particularly sea urchins, crabs, clams, abalone, mussels, etc.) it does not take very long for a group of otters to clean out a habitat of most or all of these animals. As an example, the Pismo clam beds of Monterey Bay virtually disappeared within a few years after the sea otters returned to those waters. Otters would feed on clams during the day, hang offshore at night, and return to the same spots the following day, slowly working their way northward. Off Alaska, sea otters periodically eat virtually everything edible in their habitat, after which many starve to death. This reduces their numbers, the prey return and eventually the otter population rebounds.

What are the effects on a community of removing these invertebrates? For the most part, we don't know. In some places, the removal of sea urchins by otters seems to have increased the amount of kelp, as the urchins are no longer around to eat the algae. But this is not always the case. On the other

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hand, humans who like to fish for crabs, dive for abalone, and dig for clams have been heavily affected by otters.

Does this mean we should limit the number of sea otters? Well, that is not a question a scientist can answer. A lot depends on what society wants. If society wants sea otters to live throughout their historical range (Alaska to Baja California) everyone should realize that within that range there will be relatively few lobsters, crabs, abalone, oysters, scallops, or clams. On the other hand, if society wants there to be some areas where these invertebrates are common, sea otter range and numbers will have to be limited.

HUMAN USES OF SEAWEED

Seaweeds of various sorts have been used by humans for thousands of years. People worldwide have eaten these plants, fed them to domestic animals or used them as fertilizers. One of the earliest records of human seaweed consumption (of the very important red algae *Porphyra*) occurs in a Chinese book from about 533. By about 1000, the Chinese considered *Porphyra* such a delicacy that the people of southern China annually presented the emperor with gifts of this plant. Many Asian markets sell seaweed as food, often labeled as nori (*Porphyra*), Hijiki, Wakame, Ogo (*Gracilaria*) and kombu (L*aminaria*). Thin sheets of dried seaweed are wrapped around fish, rice, or vegetables for sushi.

Today, many millions of tons of seaweed are consumed worldwide and much of it is cultivated in the ocean, primarily in Japan and China. Throughout the world, over 450 species of algae are used for food or fertilizer, in medicine or in industry. While most of these are eaten directly, either fresh, dried, or as pickles or candy, much of the harvest is processed for various products. Three examples of seaweed derivatives are *algin*, *agar*, and *carrageenan* . (We will discuss algin later when we talk about kelp harvesting.) Agar is a gelling agent found in red seaweeds, including agarweed (*Gelidium robustum*) and feather branch seaweed (*Pterocladia*). Agar is used in growing bacteria in research and medicine. It is also used in canning fish, thickening ice cream and cream cheese, and for making jams. Carrageenan is a stabilizer produced from various red algae. It, too, is used to thicken foods, such as dairy products and canned soups. It is a major component of Ronald McDonald’s favorite seaweed concoction, the McLean burger. In fact, a large part of the Philippine seaweed farming industry goes to producing carrageenan for McLeans.

Harvesting kelp, primarily giant kelp, is a major industry in California and has primarily aimed at producing one product—**algin.** Algae contains *alginic acid*, more commonly called algin or *alginates*, a substance that has the curious ability of holding large numbers of water molecules in suspension. Because it is a large plant, which lives in extensive beds at the surface, giant kelp is the perfect plant to harvest for algin. Algin is used in a bewildering array of products. When added to water-based foods (such as bottled salad dressings or ice cream), it produces a thicker, creamier consistency. When placed in such bakery products as cake mixes, the baked goods tend to have

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an improved texture and retain moisture better. Algin is even added to many beers, to stabilize the foam. Among just a few industrial applications, algin products are used to coat paper, help print textiles, produce dental impressions, and as an aid in making tablets dissolve. On ingredient lists look for algin, or sodium or calcium alginate. This is an extremely valuable commodity in California. The Kelco Company, the largest of the kelp harvesters in California today, estimates that its sales of algin alone (not including all other kelp-related products) exceeds $35 million per year.

How is Kelp Harvested?

Most kelp harvesting occurs between Monterey and San Diego using specially designed ships. These vessels slowly move through the kelp beds pushing cutting racks ahead of them. The cut kelp is gathered on conveyors and loaded aboard the vessel. Kelp harvesters are limited by law to cutting only a limited amount of the plant—the surface canopy and the fronds, floats, and stipes, which live down to about four feet below the surface. The kelp is taken to a shore-based facility where it is chopped, washed, cooked, and clarified to remove various impurities. Algin is recovered, dried, and finely ground.

Does harvesting harm giant kelp beds? Cutting the top few feet of a bed does not seem to harm the plant itself. In nature, the upper-most fronds live for six months at most, after which they begin to deteriorate and slough off. Moreover, the parts of the plant where reproduction occurs are near the plant's base, well away from the harvesting zone. In addition, photosynthesis, growth, and buoyancy are distributed along the entire length of the plant and so are not eliminated during harvest. As noted before, giant kelp grows very quickly and a bed may be harvested as many as three times a year.

Whether harvesting harms populations of other organisms associated with kelp forests is not well known. Certainly, the animals which live on the harvested kelp die after the kelp is cut. Kelp crabs and some fishes, for example, are often taken up onto the vessel with the cut kelp. However, several studies have shown no overall reduction in fishes or invertebrates in harvested forests, even though numerous organisms are removed along with the cut fronds. It is likely that, if there are negative effects on associated organisms, they are minor ones.

Kelp forests are also magnets for both sport and commercial fishermen. Sport fishermen target this habitat for a variety of species, including kelp bass (*Paralabrax clathratus*), sheephead (*S. pulcher*), various rockfishes (perhaps seven species), white seabass (*Atractoscion nobilis*), yellowtail (*Seriola lalandi*), and barracuda (*Sphyraena argentea*). Commercial fisheries include abalone (*Haliotis* spp.), red sea urchin (*S. franciscanus*) and spiny lobster (*Panulirus interruptus*).

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KELP FORESTS AND POLLUTION

Kelp plants are susceptible to a number of pollutants we put in the ocean. Some forests have been damaged or even destroyed as a result. Probably the best documented example occurred off Los Angeles near Palos Verdes during the 1940s and 1950s. Sewage discharge there contributed to the complete destruction of one of the largest kelp forests in California. Domestic wastes contain nutrients plankton need, and when plankton numbers increase they cloud the water, reducing the amount of light available to kelp plants. The sludge dumped by sewage pipes also can cloud the water, with the same effect. The kelp did not return to the area in any quantity for many years, and only recently, when sewage treatment was improved, has the forest begun to rebuild. A similar, but less drastic decline, occurred in the Point Loma kelp forest, near San Diego. Here, the bed recovered when a longer discharge pipe was built, funneling wastes away from the forest.

Oil spills seem to cause only minor or transitory damage to kelp plants. During the 1957 *Tampico tanker* spill in Baja California, which dumped massive amounts of highly toxic diesel fuel, only minor damage to kelp was noted, and within a year the forest was at least as large as before the spill. Interestingly, one of the reasons kelp growth was so high after the spill is that most of the kelp-eating animals, such as sea urchins, were killed in the spill.

WHAT IF ALL THE KELP DISAPPEARED?

To put the importance of kelp forests into perspective, what might happen if all the forests of giant kelp along a coastline just disappeared?

Smaller species of algae would immediately proliferate; their growth is usually kept in check because the thick *kelp* canopy keeps them in the shade. While it is *likely* that dense stands of these other species would develop, these algal beds would not be as massive as kelp beds because the plants do not grow anywhere near as large, they do not grow to the surface, and do not form canopies. So the first effect would probably be a reduction in the amount of algae (particularly in the middle of the water column and at the surface) available to other organisms. This would mean that because there was less stuff to live on or in, there would be fewer organisms in the area.

Are there organisms that depend solely on giant kelp? As far as we can tell, no. Some species seem to *prefer* it, but they are also found in lesser numbers around other algae. So while it is unlikely there would be a mass extinction of some species, we might expect that the numbers of some organisms would dramatically decrease when their favorite habitat disappeared. Moreover, as these organisms become less abundant, we would expect their predators would either starve or move away, seeking better hunting grounds.

There are also more subtle, but no less important, effects which might occur. For instance, the major food source of abalone is drifting pieces of giant kelp. If these disappeared, some abalone would find other algae to eat, some might survive but be weakened and have reduced reproduction or increased

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infection rates, and some might starve. We know from local disappearances of kelp forests what would take place with sea urchins. If drift kelp is not available to them, urchins leave their usual crevices and hunt for anything edible, often turning a reef into a veritable desert.

It is difficult to predict the long-term effects of dramatically changing or losing an entire habitat. Biologists worldwide, however, cite the protection of habitats as the critical element in a strategy for maintaining global bio-diversity. Kelp forests, among the most diverse of all marine habitats, certainly merit careful protection and management.

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