

dinary substance it is. Almost nothing about it can be used to make reliable predictions about the properties of other liquids and vice versa. If you knew nothing of water and based your assumptions on the behavior of compounds most chemically akin to it—hydrogen selenide or hydrogen sulphide notably—you would expect it to boil at minus 135 degrees Fahrenheit and to be a gas at room temperature.

Most liquids when chilled contract by about 10 percent. Water does too, but only down to a point. Once it is within whispering distance of freezing, it begins—perversely, beguilingly, extremely improbably—to expand. By the time it is solid, it is almost a tenth more voluminous than it was before. Because it expands, ice floats on water—"an utterly bizarre property," according to John Gribbin. If it lacked this splendid waywardness, ice would sink, and lakes and oceans would freeze from the bottom up. Without surface ice to hold heat in, the water's warmth would radiate away, leaving it even chillier and creating yet more ice. Soon even the oceans would freeze and almost certainly stay that way for a very long time, probably forever—hardly the conditions to nurture life. Thankfully for us, water seems unaware of the rules of chemistry or laws of physics.

Everyone knows that water's chemical formula is H_2O , which means that it consists of one largish oxygen atom with two smaller hydrogen atoms attached to it. The hydrogen atoms cling fiercely to their oxygen host, but also make casual bonds with other water molecules. The nature of a water molecule means that it engages in a kind of dance with other water molecules, briefly pairing and then moving on, like the ever-changing partners in a quadrille, to use Robert Kunzig's nice phrase. A glass of water may not appear terribly lively, but every molecule in it is changing partners billions of times a second. That's why water molecules stick together to form bodies like puddles and lakes, but not so tightly that they can't be easily separated as when, for instance, you dive into a pool of them. At any given moment only 15 percent of them are actually touching.

In one sense the bond is very strong—it is why water molecules can flow uphill when siphoned and why water droplets on a car hood show

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IMAGINE TRYING TO live in a world dominated by dihydrogen oxide, a compound that has no taste or smell and is so variable in its properties that it is generally benign but at other times swiftly lethal. Depending on its state, it can scald you or freeze you. In the presence of certain organic molecules it can form carbonic acids so nasty that they can strip the leaves from trees and eat the faces off statuary. In bulk, when agitated, it can strike with a fury that no human edifice could withstand. Even for those who have learned to live with it, it is an often murderous substance. We call it water.

Water is everywhere. A potato is 80 percent water, a cow 74 percent, a bacterium 75 percent. A tomato, at 95 percent, is little *but* water. Even humans are 65 percent water, making us more liquid than solid by a margin of almost two to one. Water is strange stuff. It is formless and transparent, and yet we long to be beside it. It has no taste and yet we love the taste of it. We will travel great distances and pay small fortunes to see it in sunshine. And even though we know it is dangerous and drowns tens of thousands of people every year, we can't wait to frolic in it.

Because water is so ubiquitous we tend to overlook what an extraor-

such a singular determination to bead with their partners. It is also why water has surface tension. The molecules at the surface are attracted more powerfully to the like molecules beneath and beside them than to the air molecules above. This creates a sort of membrane strong enough to support insects and skipping stones. It is what gives the sting to a belly flop.

I hardly need point out that we would be lost without it. Deprived of water, the human body rapidly falls apart. Within days, the lips vanish "as if amputated, the gums blacken, the nose withers to half its length, and the skin so contracts around the eyes as to prevent blinking." Water is so vital to us that it is easy to overlook that all but the smallest fraction of the water on Earth is poisonous to us—deadly poisonous—because of the salts within it.

We need salt to live, but only in very small amounts, and seawater contains way more—about seventy times more—salt than we can safely metabolize. A typical liter of seawater will contain only about 2.5 teaspoons of common salt—the kind we sprinkle on food—but much larger amounts of other elements, compounds, and other dissolved solids, which are collectively known as salts. The proportions of these salts and minerals in our tissues is uncannily similar to seawater—we sweat and cry seawater, as Margulis and Sagan have put it—but curiously we cannot tolerate them as an input. Take a lot of salt into your body and your metabolism very quickly goes into crisis. From every cell, water molecules rush off like so many volunteer firemen to try to dilute and carry off the sudden intake of salt. This leaves the cells dangerously short of the water they need to carry out their normal functions. They become, in a word, dehydrated. In extreme situations, dehydration will lead to seizures, unconsciousness, and brain damage. Meanwhile, the overworked blood cells carry the salt to the kidneys, which eventually become overwhelmed and shut down. Without functioning kidneys you die. That is why we don't drink seawater.

There are 320 million cubic miles of water on Earth and that is all we're ever going to get. The system is closed: practically speaking, nothing can be added or subtracted. The water you drink has been around doing its job since the Earth was young. By 3.8 billion years ago, the oceans had (at least more or less) achieved their present volumes.

The water realm is known as the hydrosphere and it is overwhelmingly oceanic. Ninety-seven percent of all the water on Earth is in the seas, the greater part of it in the Pacific, which covers half the planet and is bigger than all the landmasses put together. Altogether the Pacific holds just over half of all the ocean water (51.6 percent to be precise); the Atlantic has 23.6 percent and the Indian Ocean 21.2 percent, leaving just 3.6 percent to be accounted for by all the other seas. The average depth of the ocean is 2.4 miles, with the Pacific on average about a thousand feet deeper than the Atlantic and Indian Oceans. Altogether 60 percent of the planet's surface is ocean more than a mile deep. As Philip Ball notes, we would better call our planet not Earth but Water.

Of the 3 percent of Earth's water that is fresh, most exists as ice sheets. Only the tiniest amount—0.036 percent—is found in lakes, rivers, and reservoirs, and an even smaller part—just 0.001 percent—exists in clouds or as vapor. Nearly 90 percent of the planet's ice is in Antarctica, and most of the rest is in Greenland. Go to the South Pole and you will be standing on nearly two miles of ice, at the North Pole just fifteen feet of it. Antarctica alone has six million cubic miles of ice—enough to raise the oceans by a height of two hundred feet if it all melted. But if all the water in the atmosphere fell as rain, evenly everywhere, the oceans would deepen by only an inch.

Sea level, incidentally, is an almost entirely notional concept. Seas are not level at all. Tides, winds, the Coriolis force, and other effects alter water levels considerably from one ocean to another and within oceans as well. The Pacific is about a foot and a half higher along its western edge—a consequence of the centrifugal force created by the Earth's spin. Just as when you pull on a tub of water the water tends to flow toward the other end, as if reluctant to come with you, so the eastward spin of Earth piles water up against the ocean's western margins.

Considering the age-old importance of the seas to us, it is striking how long it took the world to take a scientific interest in them. Until well into the nineteenth century most of what was known about the oceans was based on what washed ashore or came up in fishing nets, and nearly all that was written was based more on anecdote and supposition than on

physical evidence. In the 1830s, the British naturalist Edward Forbes surveyed ocean beds throughout the Atlantic and Mediterranean and declared that there was no life at all in the seas below 2,000 feet. It seemed a reasonable assumption. There was no light at that depth, so no plant life, and the pressures of water at such depths were known to be extreme. So it came as something of a surprise when, in 1860, one of the first transatlantic telegraph cables was hauled up for repairs from more than two miles down, and it was found to be thickly encrusted with corals, clams, and other living detritus.

The first really organized investigation of the seas didn't come until 1872, when a joint expedition between the British Museum, the Royal Society, and the British government set forth from Portsmouth on a former warship called HMS *Challenger*. For three and a half years they sailed the world, sampling waters, netting fish, and hauling a dredge through sediments. It was evidently dreary work. Out of a complement of 240 scientists and crew, one in four jumped ship and eight more died or went mad—“driven to distraction by the mind-numbing routine of years of dredging” in the words of the historian Samantha Weinberg. But they sailed across almost 70,000 nautical miles of sea, collected over 4,700 new species of marine organisms, gathered enough information to create a fifty-volume report (which took nineteen years to put together), and gave the world the name of a new scientific discipline: *oceanography*. They also discovered, by means of depth measurements, that there appeared to be submerged mountains in the mid-Atlantic, prompting some excited observers to speculate that they had found the lost continent of Atlantis.

Because the institutional world mostly ignored the seas, it fell to devoted—and very occasional—amateurs to tell us what was down there. Modern deep-water exploration begins with Charles William Beebe and Otis Barton in 1930. Although they were equal partners, the more colorful Beebe has always received far more written attention. Born in 1877 into a well-to-do family in New York City, Beebe studied zoology at Columbia University, then took a job as a birdkeeper at the New York Zoological Society. Tiring of that, he decided to adopt the life of an adventurer and for the next quarter century traveled extensively through Asia and South

America with a succession of attractive female assistants whose jobs were inventively described as “historian and technician” or “assistant in fish problems.” He supported these endeavors with a succession of popular books with titles like *Edge of the Jungle* and *Jungle Days*, though he also produced some respectable books on wildlife and ornithology.

In the mid-1920s, on a trip to the Galápagos Islands, he discovered “the delights of dangling,” as he described deep-sea diving. Soon afterward he teamed up with Barton, who came from an even wealthier family, had also attended Columbia, and also longed for adventure. Although Beebe nearly always gets the credit, it was in fact Barton who designed the first bathysphere (from the Greek word for “deep”) and funded the \$12,000 cost of its construction. It was a tiny and necessarily robust chamber, made of cast iron 1.5 inches thick and with two small portholes containing quartz blocks three inches thick. It held two men, but only if they were prepared to become extremely well acquainted. Even by the standards of the age, the technology was unsophisticated. The sphere had no maneuverability—it simply hung on the end of a long cable—and only the most primitive breathing system: to neutralize their own carbon dioxide they set out open cans of soda lime, and to absorb moisture they opened a small tub of calcium chloride, over which they sometimes waved palm fronds to encourage chemical reactions.

But the nameless little bathysphere did the job it was intended to do. On the first dive, in June 1930 in the Bahamas, Barton and Beebe set a world record by descending to 600 feet. By 1934, they had pushed the record to 3,028 feet, where it would stay until after the war. Barton was confident the device was safe to a depth of 4,500 feet, though the strain on every bolt and rivet was audibly evident with each fathom they descended. At any depth, it was brave and risky work. At 3,000 feet, their little porthole was subjected to nineteen tons of pressure per square inch. Death at such a depth would have been instantaneous, as Beebe never failed to observe in his many books, articles, and radio broadcasts. Their main concern, however, was that the shipboard winch, straining to hold on to a metal ball and two tons of steel cable, would snap and send the two men plunging to the seafloor. In such an event, nothing could have saved them.

The one thing their descents didn't produce was a great deal of worthwhile science. Although they encountered many creatures that had not been seen before, the limits of visibility and the fact that neither of the intrepid aquanauts was a trained oceanographer meant they often weren't able to describe their findings in the kind of detail that real scientists craved. The sphere didn't carry an external light, merely a 250-watt bulb they could hold up to the window, but the water below five hundred feet was practically impenetrable anyway, and they were peering into it through three inches of quartz, so anything they hoped to view would have to be nearly as interested in them as they were in it. About all they could report, in consequence, was that there were a lot of strange things down there. On one dive in 1934, Beebe was startled to spy a giant serpent "more than twenty feet long and very wide." It passed too swiftly to be more than a shadow. Whatever it was, nothing like it has been seen by anyone since. Because of such vagueness their reports were generally ignored by academics.

After their record-breaking descent of 1934, Beebe lost interest in diving and moved on to other adventures, but Barton persevered. To his credit, Beebe always told anyone who asked that Barton was the real brains behind the enterprise, but Barton seemed unable to step from the shadows. He, too, wrote thrilling accounts of their underwater adventures and even starred in a Hollywood movie called *Titans of the Deep*, featuring a bathysphere and many exciting and largely fictionalized encounters with aggressive giant squid and the like. He even advertised Camel cigarettes ("They don't give me jittery nerves"). In 1948 he increased the depth record by 50 percent, with a dive to 4,500 feet in the Pacific Ocean near California, but the world seemed determined to overlook him. One newspaper reviewer of *Titans of the Deep* actually thought the star of the film was Beebe. Nowadays, Barton is lucky to get a mention.

At all events, he was about to be comprehensively eclipsed by a father-and-son team from Switzerland, Auguste and Jacques Piccard, who were designing a new type of probe called a bathyscaphe (meaning "deep boat"). Christened *Trieste*, after the Italian city in which it was built, the new device maneuvered independently, though it did little more than just go up and down. On one of its first dives, in early 1954, it descended to below

13,287 feet, nearly three times Barton's record-breaking dive of six years earlier. But deep-sea dives required a great deal of costly support, and the Piccards were gradually going broke.

In 1958, they did a deal with the U.S. Navy, which gave the Navy ownership but left them in control. Now flush with funds, the Piccards rebuilt the vessel, giving it walls five inches thick and shrinking the windows to just two inches in diameter—little more than peepholes. But it was now strong enough to withstand truly enormous pressures, and in January 1960 Jacques Piccard and Lieutenant Don Walsh of the U.S. Navy sank slowly to the bottom of the ocean's deepest canyon, the Mariana Trench, some 250 miles off Guam in the western Pacific (and discovered, not incidentally, by Harry Hess with his fathometer). It took just under four hours to fall 35,820 feet, or almost seven miles. Although the pressure at that depth was nearly 17,000 pounds per square inch, they noticed with surprise that they disturbed a bottom-dwelling flatfish just as they touched down. They had no facilities for taking photographs, so there is no visual record of the event.

After just twenty minutes at the world's deepest point, they returned to the surface. It was the only occasion on which human beings have gone so deep.

Forty years later, the question that naturally occurs is: Why has no one gone back since? To begin with, further dives were vigorously opposed by Vice Admiral Hyman G. Rickover, a man who had a lively temperament, forceful views, and, most pertinently, control of the departmental checkbook. He thought underwater exploration a waste of resources and pointed out that the Navy was not a research institute. The nation, moreover, was about to become fully preoccupied with space travel and the quest to send a man to the Moon, which made deep sea investigations seem unimportant and rather old-fashioned. But the decisive consideration was that the *Trieste* descent didn't actually achieve much. As a Navy official explained years later: "We didn't learn a hell of a lot from it, other than that we could do it. Why do it again?" It was, in short, a long way to go to find a flatfish, and expensive too. Repeating the exercise today, it has been estimated, would cost at least \$100 million.

When underwater researchers realized that the Navy had no inten-

tion of pursuing a promised exploration program, there was a pained outcry. Partly to placate its critics, the Navy provided funding for a more advanced submersible, to be operated by the Woods Hole Oceanographic Institution of Massachusetts. Called *Alvin*, in somewhat contracted honor of the oceanographer Allyn C. Vine, it would be a fully maneuverable minisubmarine, though it wouldn't go anywhere near as deep as the *Trieste*. There was just one problem: the designers couldn't find anyone willing to build it. According to William J. Broad in *The Universe Below*: "No big company like General Dynamics, which made submarines for the Navy, wanted to take on a project disparaged by both the Bureau of Ships and Admiral Rickover, the gods of naval patronage." Eventually, not to say improbably, *Alvin* was constructed by General Mills, the food company, at a factory where it made the machines to produce breakfast cereals.

As for what else was down there, people really had very little idea. Well into the 1950s, the best maps available to oceanographers were overwhelmingly based on a little detail from scattered surveys going back to 1929 grafted onto, essentially an ocean of guesswork. The Navy had excellent charts with which to guide submarines through canyons and around guyots, but it didn't wish such information to fall into Soviet hands, so it kept its knowledge classified. Academics therefore had to make do with sketchy and antiquated surveys or rely on hopeful surmise. Even today our knowledge of the ocean floors remains remarkably low resolution. If you look at the Moon with a standard backyard telescope you will see substantial craters—Fracastorius, Blaucanus, Zach, Planck, and many others familiar to any lunar scientist—that would be unknown if they were on our own ocean floors. We have better maps of Mars than we do of our own seabeds.

At the surface level, investigative techniques have also been a trifle ad hoc. In 1994, thirty-four thousand ice hockey gloves were swept overboard from a Korean cargo ship during a storm in the Pacific. The gloves washed up all over, from Vancouver to Vietnam, helping oceanographers to trace currents more accurately than they ever had before.

Today *Alvin* is nearly forty years old, but it still remains America's premier research vessel. There are still no submersibles that can go anywhere

near the depth of the Mariana Trench and only five, including *Alvin*, that can reach the depths of the "abyssal plain"—the deep ocean floor—that covers more than half the planet's surface. A typical submersible costs about \$25,000 a day to operate, so they are hardly dropped into the water on a whim, still less put to sea in the hope that they will randomly stumble on something of interest. It's rather as if our firsthand experience of the surface world were based on the work of five guys exploring on garden tractors after dark. According to Robert Kunzig, humans may have scrutinized "perhaps a millionth or a billionth of the sea's darkness. Maybe less. Maybe much less."

But oceanographers are nothing if not industrious, and they have made several important discoveries with their limited resources—including, in 1977, one of the most important and startling biological discoveries of the twentieth century. In that year *Alvin* found teeming colonies of large organisms living on and around deep-sea vents off the Galápagos Islands—tube worms over ten feet long, clams a foot wide, shrimps and mussels in profusion, wriggling spaghetti worms. They all owed their existence to vast colonies of bacteria that were deriving their energy and sustenance from hydrogen sulfides—compounds profoundly toxic to surface creatures—that were pouring steadily from the vents. It was a world independent of sunlight, oxygen, or anything else normally associated with life. This was a living system based not on photosynthesis but on chemosynthesis, an arrangement that biologists would have dismissed as preposterous had anyone been imaginative enough to suggest it.

Huge amounts of heat and energy flow from these vents. Two dozen of them together will produce as much energy as a large power station, and the range of temperatures around them is enormous. The temperature at the point of outflow can be as much as 760 degrees Fahrenheit, while a few feet away the water may be only two or three degrees above freezing. A type of worm called an alvinellid was found living right on the margins, with the water temperature 140 degrees warmer at its head than at its tail. Before this it had been thought that no complex organisms could survive in water warmer than about 130 degrees, and here was one that was surviving warmer temperatures than that *and* extreme cold to

boot. The discovery transformed our understanding of the requirements for life.

It also answered one of the great puzzles of oceanography—something that many of us didn't realize was a puzzle—namely, why the oceans don't grow saltier with time. At the risk of stating the obvious, there is a lot of salt in the sea—enough to bury every bit of land on the planet to a depth of about five hundred feet. Millions of gallons of fresh water evaporate from the ocean daily, leaving all their salts behind, so logically the sea ought to grow more salty with the passing years, but they don't. Something takes an amount of salt out of the water equivalent to the amount being put in. For the longest time, no one could figure out what could be responsible for this.

Alvin's discovery of the deep-sea vents provided the answer. Geophysicists realized that the vents were acting much like the filters in a fish tank. As water is taken down into the crust, salts are stripped from it, and eventually clean water is blown out again through the chimney stacks. The process is not swift—it can take up to ten million years to clean an ocean—but it is marvelously efficient as long as you are not in a hurry.

Perhaps nothing speaks more clearly of our psychological remoteness from the ocean depths than that the main expressed goal for oceanographers during International Geophysical Year of 1957-58 was to study "the use of ocean depths for the dumping of radioactive wastes." This wasn't a secret assignment, you understand, but a proud public boast. In fact, though it wasn't much publicized, by 1957-58 the dumping of radioactive wastes had already been going on, with a certain appalling vigor, for over a decade. Since 1946, the United States had been ferrying fifty-five-gallon drums of radioactive gunk out to the Farallon Islands, some thirty miles off the California coast near San Francisco, where it simply threw them overboard.

It was all quite extraordinarily sloppy. Most of the drums were exactly the sort you see rusting behind gas stations or standing outside factories, with no protective linings of any type. When they failed to sink, which was

usually, Navy gunners riddled them with bullets to let water in (and, of course, plutonium, uranium, and strontium out). Before it was halted in the 1990s, the United States had dumped many hundreds of thousands of drums into about fifty ocean sites—almost fifty thousand of them in the Farallons alone. But the U.S. was by no means alone. Among the other enthusiastic dumpers were Russia, China, Japan, New Zealand, and nearly all the nations of Europe.

And what effect might all this have had on life beneath the seas? Well, little, we hope, but we actually have no idea. We are astoundingly, sumptuously, radiantly ignorant of life beneath the seas. Even the most substantial ocean creatures are often remarkably little known to us—including the most mighty of them all, the great blue whale, a creature of such leviathan proportions that (to quote David Attenborough) its "tongue weighs as much as an elephant, its heart is the size of a car and some of its blood vessels are so wide that you could swim down them." It is the most gargantuan beast that Earth has yet produced, bigger even than the most cumbersome dinosaurs. Yet the lives of blue whales are largely a mystery to us. Much of the time we have no idea where they are—where they go to breed, for instance, or what routes they follow to get there. What little we know of them comes almost entirely from eavesdropping on their songs, but even these are a mystery. Blue whales will sometimes break off a song, then pick it up again at the same spot six months later. Sometimes they strike up with a new song, which no member can have heard before but which each already knows. How they do this is not remotely understood. And these are animals that must routinely come to the surface to breathe.

For animals that need never surface, obscurity can be even more tantalizing. Consider the fabled giant squid. Though nothing on the scale of the blue whale, it is a decidedly substantial animal, with eyes the size of soccer balls and trailing tentacles that can reach lengths of sixty feet. It weighs nearly a ton and is Earth's largest invertebrate. If you dumped one in a normal household swimming pool, there wouldn't be much room for anything else. Yet no scientist—no person as far as we know—has ever seen a giant squid alive. Zoologists have devoted careers to trying to cap-

ture, or just glimpse, living giant squid and have always failed. They are known mostly from being washed up on beaches—particularly, for unknown reasons, the beaches of the South Island of New Zealand. They must exist in large numbers because they form a central part of the sperm whale's diet, and sperm whales take a lot of feeding.*

According to one estimate, there could be as many as thirty million species of animals living in the sea, most still undiscovered. The first hint of how abundant life is in the deep seas didn't come until as recently as the 1960s with the invention of the epibenthic sled, a dredging device that captures organisms not just on and near the seafloor but also buried in the sediments beneath. In a single one-hour trawl along the continental shelf, at a depth of just under a mile, Woods Hole oceanographers Howard Sandler and Robert Hessler netted over 25,000 creatures—worms, starfish, sea cucumbers, and the like—representing 365 species. Even at a depth of three miles, they found some 3,700 creatures representing almost 200 species of organism. But the dredge could only capture things that were too slow or stupid to get out of the way. In the late 1960s a marine biologist named John Isaacs got the idea to lower a camera with bait attached to it, and found still more, in particular dense swarms of writhing hagfish, a primitive eel-like creature, as well as darting shoals of grenadier fish. Where a good food source is suddenly available—for instance, when a whale dies and sinks to the bottom—as many as 390 species of marine creature have been found dining off it. Interestingly, many of these creatures were found to have come from vents up to a thousand miles distant. These included such types as mussels and clams, which are hardly known as great travelers. It is now thought that the larvae of certain organisms may drift through the water until, by some unknown chemical means, they detect that they have arrived at a food opportunity and fall onto it.

*The indigestible parts of giant squid, in particular their beaks, accumulate in sperm whales' stomachs into the substance known as ambergris, which is used as a fixative in perfumes. The next time you spray on Chanel No. 5 (assuming you do), you may wish to reflect that you are dousing yourself in distillate of unseen sea monster.

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So why, if the seas are so vast, do we so easily overtax them? Well, to begin with, the world's seas are not uniformly bounteous. Altogether less than a tenth of the ocean is considered naturally productive. Most aquatic species like to be in shallow waters where there is warmth and light and an abundance of organic matter to prime the food chain. Coral reefs, for instance, constitute well under 1 percent of the ocean's space but are home to about 25 percent of its fish.

Elsewhere, the oceans aren't nearly so rich. Take Australia. With over 20,000 miles of coastline and almost nine million square miles of territorial waters, it has more sea lapping its shores than any other country, yet, as Tim Flannery notes, it doesn't even make it into the top fifty among fishing nations. Indeed, Australia is a large net importer of seafood. This is because much of Australia's waters are, like much of Australia itself, essentially desert. (A notable exception is the Great Barrier Reef off Queensland, which is sumptuously fecund.) Because the soil is poor, it produces little in the way of nutrient-rich runoff.

Even where life thrives, it is often extremely sensitive to disturbance. In the 1970s, fishermen from Australia and, to a lesser extent, New Zealand discovered shoals of a little-known fish living at a depth of about half a mile on their continental shelves. They were known as orange roughy, they were delicious, and they existed in huge numbers. In no time at all, fishing fleets were hauling in forty thousand metric tons of roughy a year. Then marine biologists made some alarming discoveries. Roughy are extremely long lived and slow maturing. Some may be 150 years old; any roughy you have eaten may well have been born when Victoria was Queen. Roughy have adopted this exceedingly unhurried lifestyle because the waters they live in are so resource-poor. In such waters, some fish spawn just once in a lifetime. Clearly these are populations that cannot stand a great deal of disturbance. Unfortunately, by the time this was realized the stocks had been severely depleted. Even with careful management it will be decades before the populations recover, if they ever do.

Elsewhere, however, the misuse of the oceans has been more wanton

than inadvertent. Many fishermen "fin" sharks—that is, slice their fins off, then dump them back into the water to die. In 1998, shark fins sold in the Far East for over \$250 a pound. A bowl of shark fin soup retailed in Tokyo for \$100. The World Wildlife Fund estimated in 1994 that the number of sharks killed each year was between 40 million and 70 million.

As of 1995, some 37,000 industrial-sized fishing ships, plus about a million smaller boats, were between them taking twice as many fish from the sea as they had just twenty-five years earlier. Trawlers are sometimes now as big as cruise ships and haul behind them nets big enough to hold a dozen jumbo jets. Some even use spotter planes to locate shoals of fish from the air.

It is estimated that about a quarter of every fishing net hauled up contains "by-catch"—fish that can't be landed because they are too small or of the wrong type or caught in the wrong season. As one observer told the *Economist*: "We're still in the Dark Ages. We just drop a net down and see what comes up." Perhaps as much as twenty-two million metric tons of such unwanted fish are dumped back in the sea each year, mostly in the form of corpses. For every pound of shrimp harvested, about four pounds of fish and other marine creatures are destroyed.

Large areas of the North Sea floor are dragged clean by beam trawlers as many as seven times a year, a degree of disturbance that no ecosystem can withstand. At least two-thirds of species in the North Sea, by many estimates, are being overfished. Across the Atlantic things are no better. Halibut once abounded in such numbers off New England that individual boats could land twenty thousand pounds of it in a day. Now halibut is all but extinct off the northeast coast of North America.

Nothing, however, compares with the fate of cod. In the late fifteenth century, the explorer John Cabot found cod in incredible numbers on the eastern banks of North America—shallow areas of water popular with bottom-feeding fish like cod. Some of these banks were vast. Georges Banks off Massachusetts is bigger than the state it abuts. The Grand Banks off Newfoundland is bigger still and for centuries was always dense with cod. They were thought to be inexhaustible. Of course they were anything but.

By 1960, the number of spawning cod in the north Atlantic had fallen

to an estimated 1.6 million metric tons. By 1990 this had sunk to 22,000 metric tons. In commercial terms, the cod were extinct. "Fishermen," wrote Mark Kurlansky in his fascinating history, *Cod*, "had caught them all." The cod may have lost the western Atlantic forever. In 1992, cod fishing was stopped altogether on the Grand Banks, but as of last autumn, according to a report in *Nature*, stocks had not staged a comeback. Kurlansky notes that the fish of fish fillets and fish sticks was originally cod, but then was replaced by haddock, then by redfish, and lately by Pacific pollock. These days, he notes drily, "fish" is "whatever is left."

Much the same can be said of many other seafoods. In the New England fisheries off Rhode Island, it was once routine to haul in lobsters weighing twenty pounds. Sometimes they reached thirty pounds. Left unmolested, lobsters can live for decades—as much as seventy years, it is thought—and they never stop growing. Nowadays few lobsters weigh more than two pounds on capture. "Biologists," according to the *New York Times*, "estimate that 90 percent of lobsters are caught within a year after they reach the legal minimum size at about age six." Despite declining catches, New England fishermen continue to receive state and federal tax incentives that encourage them—in some cases all but compel them—to acquire bigger boats and to harvest the seas more intensively. Today fishermen of Massachusetts are reduced to fishing the hideous hagfish, for which there is a slight market in the Far East, but even their numbers are now falling.

We are remarkably ignorant of the dynamics that rule life in the sea. While marine life is poorer than it ought to be in areas that have been overfished, in some naturally impoverished waters there is far more life than there ought to be. The southern oceans around Antarctica produce only about 3 percent of the world's phytoplankton—far too little, it would seem, to support a complex ecosystem, and yet it does. Crab-eater seals are not a species of animal that most of us have heard of, but they may actually be the second most numerous large species of animal on Earth, after humans. As many as fifteen million of them may live on the pack ice around Antarctica. There are also perhaps two million Weddell seals, at least half a million emperor penguins, and maybe as many as four million

Adélie penguins. The food chain is thus hopelessly top heavy, but somehow it works. Remarkably no one knows how.

All this is a very roundabout way of making the point that we know very little about Earth's biggest system. But then, as we shall see in the pages remaining to us, once you start talking about life, there is a great deal we don't know, not least how it got going in the first place.

19 THE RISE OF LIFE

IN 1953, STANLEY MILLER, a graduate student at the University of Chicago, took two flasks—one containing a little water to represent a primeval ocean, the other holding a mixture of methane, ammonia, and hydrogen sulphide gases to represent Earth's early atmosphere—connected them with rubber tubes, and introduced some electrical sparks as a stand-in for lightning. After a few days, the water in the flasks had turned green and yellow in a hearty broth of amino acids, fatty acids, sugars, and other organic compounds. "If God didn't do it this way," observed Miller's delighted supervisor, the Nobel laureate Harold Urey, "He missed a good bet."

Press reports of the time made it sound as if about all that was needed now was for somebody to give the whole a good shake and life would crawl out. As time has shown, it wasn't nearly so simple. Despite half a century of further study, we are no nearer to synthesizing life today than we were in 1953 and much further away from thinking we can. Scientists are now pretty certain that the early atmosphere was nothing like as primed for development as Miller and Urey's gaseous stew, but rather was a much less reactive blend of nitrogen and carbon dioxide. Repeating Miller's experiments with these more challenging inputs has so far produced only