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Sweeping The Ocean Floor

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Strange sea creatures caught on film for the first time

by Robert Kunzig

In bays along the coast of Antarctica, thick shelves of floating ice extend tens or hundreds of miles out from the shoreline. Hidden beneath those shelves are sheltered waters that until recently had been almost entirely unexplored. Now that is changing.

In 2002 a 1,250-square-mile chunk of the Larsen Ice Shelf disintegrated in a matter of weeks. The event became a symbol of a warming globe, but it also presented a sudden opportunity. In January of this year, the German research vessel Polarstern settled in where the Larsen shelf had crumbled, and researchers on board conducted the first detailed biological survey of one of the most inaccessible ecosystems on Earth.

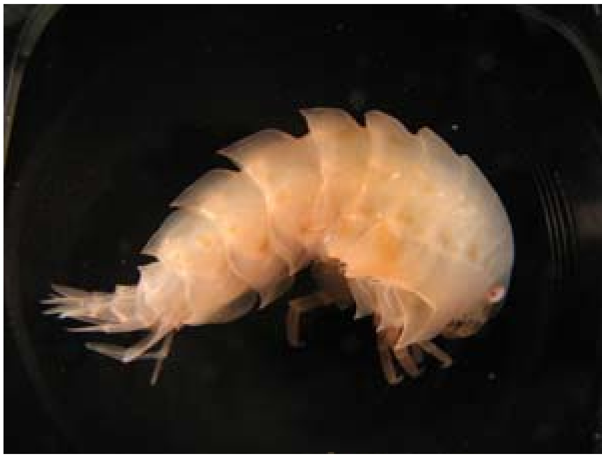

15 new amphipod species including Eusirus was found beneath Larson B Ice Shelf.

Image courtesy of C. D'Udeken,
Royal Belgium Instit. for Natural Sciences, 2007

The expedition was part of a 10-year research project called the Census of Marine Life, a loose collaboration of more than 2,000 researchers from 80 countries who are organizing dozens of expeditions to all corners of the planet. They are motivated by the humbling realization that our knowledge of undersea life as a whole is only slightly less sketchy than our knowledge of life under those Antarctic ice shelves: Even where the water is not covered by ice, its sheer volume—not to mention the difficulty of seeing and moving through it—means that it is nearly all aqua incognita. The ocean contains 320 million cubic miles of water covering 140 million miles of seafloor, more than twice the area of all the continents combined, and we've only had a look at tiny bits of it. "If you ask, 'What lives in the middle of the Atlantic?' nobody knows," says Jesse Ausubel, an environmental researcher at Rockefeller University and at the Alfred P. Sloan Foundation, which launched the $650 million Census of Marine Life.

By 2010 the census aims to deliver the best answer yet to that question. One should not picture it as a fleet of ships steaming up and down the ocean in a regular grid, counting every fish, crab, and worm—even $650 million won't buy that. Instead the census consists of 17 separate subprojects, each one a well-organized raid on a huge but well-defined realm of ignorance. There is a census of coastal waters and a census of the abyssal plains, a census of coral reefs and a census of seamounts. There is a census of microbes, of drifting animals small and large—the zooplankton—and of large swimmers like tuna and blue whales.

The ocean probably harbors millions of species of organisms, but right now only 230,000 have names. When the census is completed, it will have added thousands more to that list. Although the overwhelming majority will be nameless still, we will have a much better idea of how many there are, where they live, and how abundant the major groups are.



Amphipod, Epimeria was found beneath Larson B Ice Shelf.

Image courtesy of C. D'Udeken,
Royal Belgium Instit. for Natural Sciences, 2007

Ship by ship, voyage by voyage, ocean scientists will taste the pleasure that in January 2007 welcomed Julian Gutt of the Alfred Wegener Institute in Bremerhaven, Germany, as he sat on the Polarstern watching video images of the seafloor transmitted by a robot dangling from the ship: the joy of seeing what no one has seen before. In this case the researchers weren't expecting to find much that was alive. Organisms tend to grow and move slowly on the ocean floor, where food is scarce and temperatures hover just above freezing. Moreover, it seemed likely that large parts of the Larsen seabed would have been scoured by icebergs from the collapsing shelf. "I was crossing my fingers that there would be any animals there at all," Gutt says.

In fact, Gutt saw a vibrant scene: hundreds of sea squirts, the kind of animal—so characteristic of the deep—for which analogies invariably seem strained. They resemble gelatinous tulips, except that they happen to be chordates, animals distantly related to us. Gutt and his colleagues also saw herds of sea cucumbers—imagine sluglike water balloons crawling en masse over the seafloor. The sea squirts, he thinks, are recent colonizers from open water, but the sea cucumbers are probably remnants of the original ecosystem from before the collapse of the Larsen Ice Shelf. Why these creatures have flourished in forbidding conditions where others could not survive, Gutt does not know.

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For all its unplumbed depths, the ocean is a rather simple machine. Light from the sun comes in at the top. Nutrients, primarily nitrogen and phosphorus, are brought from the land by rivers and are stirred up from the bottom mud by upwelling currents.

Floating single-celled plants, the phytoplankton, take the sunlight and the nutrients and combine them with carbon dioxide to make organic matter. The single-celled plants are eaten by zooplankton, which are then eaten by larger things, and so on, up to the familiar tuna and nurse sharks and gray whales. Floating in the water among all these things are myriad bacteria—there are perhaps a billion cells in every liter. These bacteria degrade dead plankton and fish excrement, recycling the carbon, nitrogen, phosphorus, and other elements back into the water. Census scientists estimate that more than 90 percent of the 145 billion tons of life in the sea consists of microbes, either phytoplankton or bacteria.

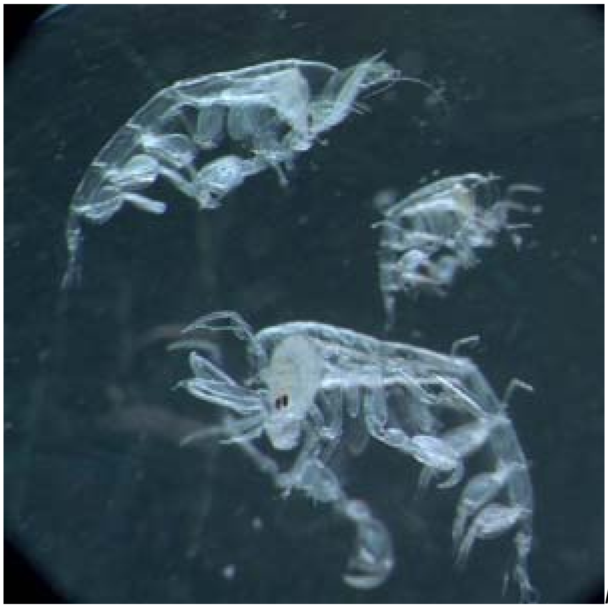
Phronima, a shrimplike amphipod, was found in mostly lifeless waters in the middle of the North Atlantic.

Image coutesy of R. Hopcroft,
University of Alaska Fairbanks © 2006

Some of the dead matter escapes the degrading microbes and sinks into the deeper, darker layers of the ocean. On the way down, it nourishes another population of animals—some fish, but also a huge array of gooey gelatinous things, known to their few scientific friends as jellies. Jellyfish proper, the medusae, are just one kind. They are familiar because they often venture into the shallows where humans paddle about. There are also the ctenophores, or comb jellies, with their eight rows of tiny rippling paddles; cylindrical salps that swim by jet propulsion; and floating snails that catch their food by casting large nets of mucus.

Many of these animals are able to light up like fireflies—whether to scare off predators or attract a mate is not entirely clear. Descending in a submersible from the sunlit surface waters into the deep and utter dark of the abyss, one sees these bioluminescent flickers, like flashbulbs in a darkened concert hall.

Then there is the bottom. The seafloor is not a single place; its topography is every bit as varied as that of dry land. A rugged chain of volcanic mountains, the midocean ridge, runs down the center of the Atlantic, around Africa into the Indian Ocean, between Australia and Antarctica, and across the South Pacific, then up the East Pacific to California, where it becomes the San Andreas Fault. The ridge rises as high as 15,000 feet above the surrounding abyssal plains. Here and there, those hilly plains are interrupted by underwater mountains called seamounts. In certain places along the rim of the oceans, especially the Pacific Rim, the seafloor descends abruptly into deep trenches. The most extreme, the Mariana Trench near the Philippines, plunges nearly seven miles, far deeper than Everest is tall. In 1960 Swiss explorer Jacques Piccard and American Navy lieutenant Don Walsh landed on its bottom in a primitive submarine, the Trieste, and looked out their tiny porthole for a few minutes. They saw a fish, or maybe it was a sea cucumber. There is life everywhere in the ocean, on every patch of ground, in every ounce of water.

The deep seafloor is perfectly dark—sunlight is completely extinguished at a depth of 3,000 feet—and so it has no plants. Life there is sustained by the intermittent rain of dead organic matter from the surface waters. In places like the North Atlantic, where plankton bloom lushly in the spring, oceanographers find patches of green stuff on the ocean bed, a mile or two below. Sea cucumbers, one of the most common deep-sea animals, crawl through the stuff and vacuum it up. When a fish corpse reaches the bottom, every bit of flesh and bone is slowly scavenged by eel-like hagfish, starfish, and swarms of tiny crustaceans called amphipods. Even where the food is not so rich, the seafloor is not lifeless; everywhere it is churned by bristle worms and nematodes and pill-bug-like isopods. Life at the bottom may be sparse, but it is thorough. Every particle of mud passes through a worm gut several times at least.

For more than a century, after deep-sea studies got going in earnest in the 1870s with the round-the-world expedition of the British ship Challenger, biologists thought that was all there was to it. Then in 1977, two geochemists—Jack Corliss and John Edmond, diving in the submersible Alvin—discovered the first hydrothermal vent, or volcanic hot spring, on the ocean floor.

They saw an astonishing scene around the vent. Clustered there, on the midocean ridge near the Galápagos Islands, were giant clams and mussels and six-foot-long tube worms, anchored to the ground and sticking upright. The tubes were white as ivory, with scarlet plumes at their tips that retracted as the sub approached. None of these species had ever been documented before.

> Scientists estimate that there were up to 10 million animal species living on the ocean floor. If so, the deep was as diverse as the tropical rain forest.

The strange organisms of the Galápagos rift turned out to be a whole new type of ecosystem. The base of their food chain was not plants that captured the energy of the sun but chemosynthetic bacteria that captured the energy of the volcano. Similar hydrothermal vent communities were eventually found at dozens of other points on the midocean ridge. Biologists, including some who had never thought much about the deep before, descended on them with fascination—and relief. It didn't take much work to convince the public and the funding agencies that these weird beasts were worth studying, so out-of-reach money suddenly became available. But in the ensuing rush, it was easy to forget that there was still a vast, cold, unknown ocean out there.

Fred Grassle never forgot. He had been one of the first scientists to get a good look at the Galápagos hot springs. A biologist from Rutgers University in New Jersey specializing in polychaetes—tiny caterpillar-like things, also known as bristle worms—he found himself staring out Alvin's porthole at tube worms almost as tall as he was. He was as amazed as anyone, but he soon went back to the larger problem of studying all the rest of the ocean. In the 1980s, he and his colleague Nancy Maciolek of Battelle Ocean Sciences in Massachusetts used a simple device called a box corer to collect undisturbed square-foot samples of seafloor mud. Judging from how many new species they found each time they lowered their device 7,000 feet onto the continental slope off New Jersey, Grassle and Maciolek estimated that there were up to 10 million animal species living on the ocean floor. If so, the deep was as diverse as the tropical rain forest.

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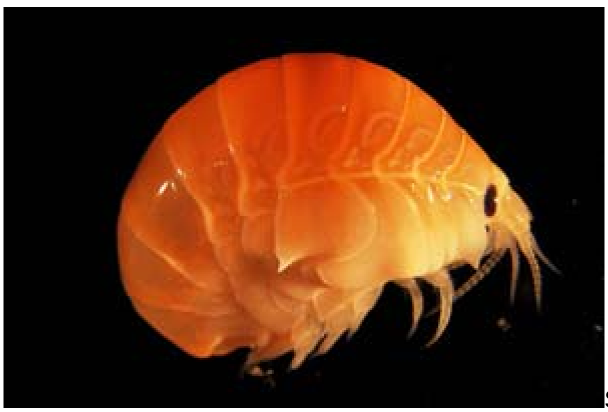

Shakletonia, another amphipod found beneath Larson B Ice Shelf

Image courtesy of C. D'Udeken,
Royal Belgium Instit. for Natural Sciences, 2007

Grassle tried hard to get people excited about his work. He did not have much luck until he went to see Jesse Ausubel, who calls himself an environmental scientist and systems analyst but whose real talent is that he is a big-picture man, an organizer, and a congenital optimist. Early in his career he began studying environmental problems. "I'm going to be doing this for 40 years," he decided, "and I don't want to just go around saying 'Terrible things could happen.'"

Terrible things are in fact happening to the ocean, as Grassle told Ausubel when they met. It was July 2, 1996, and they spent most of the day together in Woods Hole, Massachusetts, where Grassle had once worked at the Oceanographic Institution and where Ausubel has a summer office. A hundred miles to the east, on Georges Bank, the codfish stock had recently collapsed, as had the much larger one on the Grand Banks off Newfoundland; regulators had been forced to close both of those rich and historic fisheries. The amount we know about the marine species we depend on, Grassle told Ausubel, is minimal. The amount we don't know about the rest of the ocean, on the other hand, is astronomical.

Ausubel took that as a challenge. The Sloan Foundation had recently sponsored a Digital Sky Survey—a systematic census of the stars. What did Grassle think, Ausubel asked, about doing a census of the fishes? Grassle thought it was a splendid idea, as long as it didn't get diverted into something strictly utilitarian—a census of seafood—and as long as it included all the other things that lived in the ocean, including obscure but biologically important organisms like polychaetes. The Census of Marine Life was born in 2000. "It is what it says it is," Ausubel says. "If you pick up any textbook, there isn't one that can tell you what lives in the ocean. From microbes to mammals, from near the shore to the open ocean, from the bottom to the top—what lives there. It's a very simple idea."

Finding out what lives there doesn't just mean finding new species; it also means tracking the species we already know to find out where they go. Even highly visible marine animals lead invisible lives, far from shore or underwater or both. Stanford University biologist Barbara Block and her colleagues on a census project called Tagging of Pacific Pelagics are using microchips and satellite transmitters to penetrate those secrets. So far the researchers have tagged 2,400 animals belonging to 23 species. Some tags pop to the surface at a preset time, like a flare, and radio the animal's position back to the team via satellite. Other animals—sharks, elephant seals, whales, leatherback turtles—are equipped with tags that phone home each time the creatures surface. The tracking project's Web site contains a map of those animals' movements, a tangled mesh of colored lines that is updated daily.

Such maps have revealed astonishing migrations. Bluefin tuna born in the Mediterranean cross the Atlantic to feed for a few years up and down the east coast of North America, mingling there with bluefins born in the Gulf of Mexico. Bluefins in the Pacific, on the other hand, feed off California for a few years before crossing the ocean to their breeding grounds off Japan—where a single one can fetch $175,000 on the Tokyo market. And white sharks, once thought to spend most of their time hunting seals and surfers off the California coast, actually head west in winter, to the open sea. For a few months, the sharks hang out in a patch of ocean near Hawaii that is low on food and any other obvious attraction. "My students call it the White Shark Café," Block says.

But most of the ocean's diversity probably isn't hiding; it is teeming everywhere, undiscovered simply because it is so small. That is why Mitchell Sogin of the Marine Biological Laboratory in Woods Hole is directing the Census of Marine Microbes. The old way to search for microbial life in the ocean, he explains, was to isolate individual species by growing them in laboratory cultures. Biologists have identified around 5,000 species that way. But over the past 15 years or so, researchers have begun to realize that those 5,000 are just the hardy few that happen to be easy to keep alive in the lab.

A newer, far less selective way of plumbing the ocean's microscopic diversity is to isolate individual genes, not individual microbes. Researchers use a small piece of the gene for ribosomal RNA, or rRNA—a gene that is distinct in every species—to grab all the rRNA genes that are present in a liter of seawater. Then they determine the sequence of as many of those genes as their grant money will allow—typically around a thousand, coming from a thousand bacterial cells—and use that information to estimate how many different kinds of bacteria are present in the sample.

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Sogin is now supercharging this approach. By using faster sequencing machines and targeting only one highly variable part of the rRNA gene, he and his team can sequence 200,000 pieces of DNA from a single liter. As a result, the amount of diversity they find has soared. In one sample from the deep North Atlantic Ocean, they have found more than 60,000 kinds of bacteria.

One intriguing discovery, Sogin says, is that in each sample he has studied so far there are always a few dominant kinds of microbes but also thousands more that are rare. Moreover, at each station—or even at different depths at the same station—there is a different suite of rare microbes. The large number of rare microbial species suggests that they have an important role in the oceanic ecosystem. Sogin suggests these rare species might function as a genetic archive, a fail-safe against environmental disaster.

Over many millions of years, he explains, Earth has undergone repeated environmental cataclysms. "Global warming, asteroid impact, or whatever it is—those events threaten the survival of the microorganisms. This might be a way for them to cope," Sogin says. If there are tens of thousands of rare microbes floating in the water, all with different genes and correspondingly different abilities, there will always be a few that are adapted to the new environment. The dominant might become rare, the rare might become dominant, but the kingdom as a whole persists, albeit with an altered mix of species, which in turn alters the elemental cycles that determine the basic life chemistry of the sea.


A 2005 mission to the ice-covered Canada Basin, some of the world's oldest waters, exposed a new type of larvacean.

Image coutesy of R. Hopcroft, University of Alaska Fairbanks © 2006

If so, the invisible and barely explored world of marine microbes may end up touching our own world in ways we cannot foresee. As the oceans grow warmer and more acidic from our emissions of carbon dioxide, we may once again shift the microbial balance in the ocean. “A minor change in acidity could have radical impacts, and that could lead to a cascade of effects on climate change,” Sogin says.

The realm of the very deep in the sea is as elusive as the realm of the very small—and rare species seem to be the norm there too. Away from the rocky slopes of the seamounts and midocean ridges, the ocean floor is everywhere cold and muddy, so scientists long assumed that fauna would be pretty much the same worldwide. Such “cosmopolitan” animals do exist: There are species of foraminifera (single-celled organisms with shells) that live both in Arctic as well as Antarctic mud, thousands of miles apart.

But in a series of expeditions to the Antarctic aboard the Polarstern, Angelika Brandt of the University of Hamburg has encountered different sorts of organisms. She focused on the deep seafloor, well beyond the ice shelves and the continental shelf that were her compatriot Julian Gutt’s targets. Her specialty is isopods, segmented crustaceans that thrive in the deepest stretches of the ocean. At 40 stations in the Southern Ocean, dragging a sled with a net through more than three acres of mud, Brandt found 674 species of isopod. More than 500 were new to science.

“It was astonishing,” says Brandt. “It was really high diversity.” The pattern of diversity was reminiscent of the pattern Sogin saw with his bacteria. “We had only a few species that were dominant—and many that were very, very rare. More than 50 percent of the species were found at only a single station,” she says. In many cases there was only a single specimen, which raises the question of how those poor isolated creatures find a mate.

For all its scope, even the census won’t be able to describe each species of isopod or polychaete that squirms in the deep-sea mud. But it will at least compile information on most of the species of life in the sea that are known and have been named, and estimate their geographic range. It will also estimate the abundance, in tons, of the large taxonomic groups like the crustaceans. Finally, it will try to say something about what used to live in the ocean, before we overfished and polluted so much of it, and what is likely to persist there now that it is so heavily under our influence. Last year a census study projected that, if current trends continue, all commercially fished species will follow the cod into collapse by 2050.

At present, our impact on the ocean vastly outstrips our knowledge of it. One of the tasks of the census, says Ausubel, is to try to right that balance. There is a lot we can learn just by removing our blinders, a lot that is “invisible” just because we have not looked. Maybe something as weird and new as hydrothermal vents will turn up in some place yet unexplored.

“Nobody had ever looked into the deep sea off Antarctica,” Brandt says. “Nobody ever went there to say, ‘Look, this is there.’ We tried to hypothesize about what might be there. It’s an enormous area, and it’s almost unknown.”