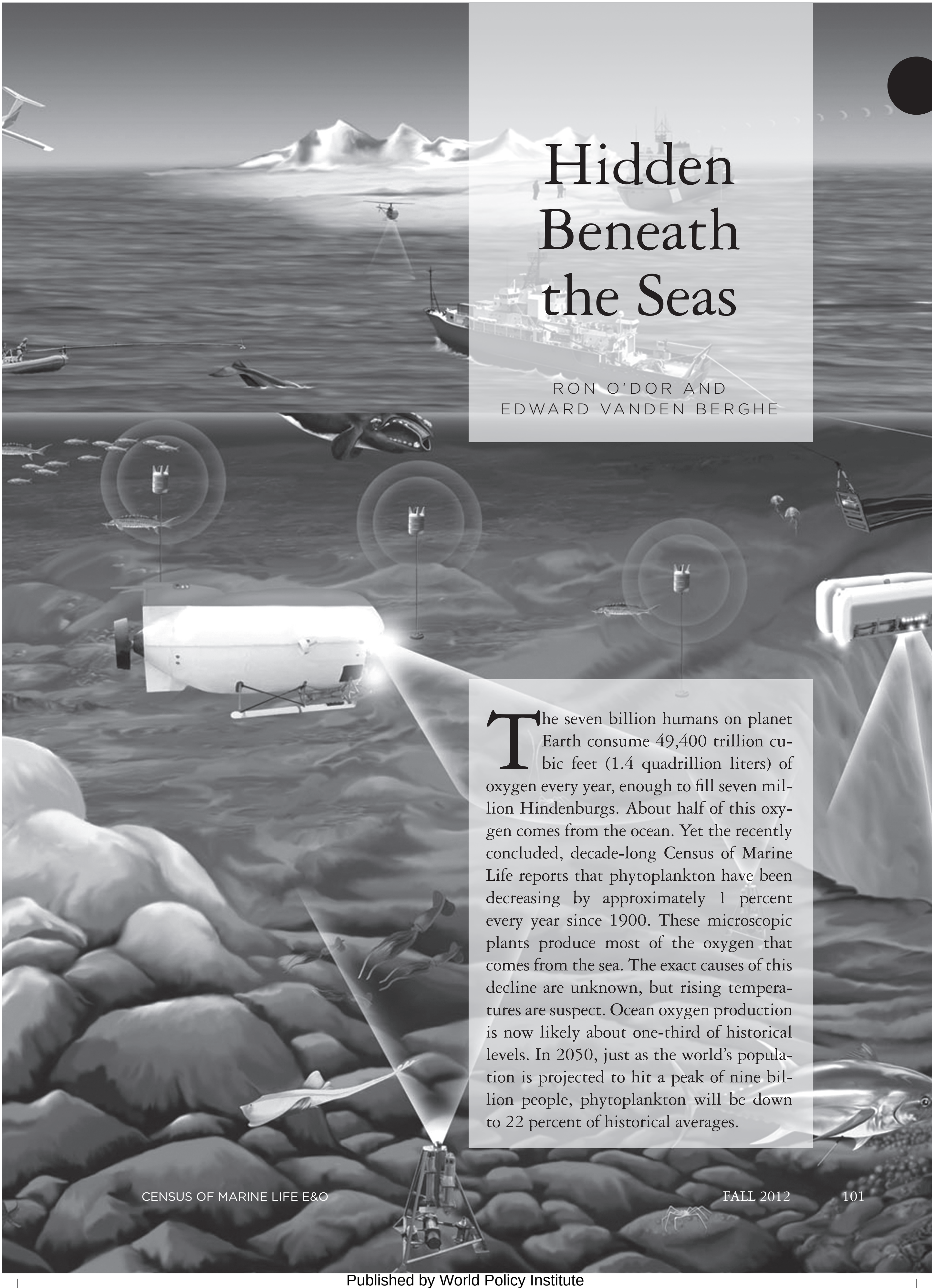

Hidden Beneath the Seas

RON O'DOR AND
EDWARD VANDEN BERGHE

The seven billion humans on planet Earth consume 49,400 trillion cubic feet (1.4 quadrillion liters) of oxygen every year, enough to fill seven million Hindenburgs. About half of this oxygen comes from the ocean. Yet the recently concluded, decade-long Census of Marine Life reports that phytoplankton have been decreasing by approximately 1 percent every year since 1900. These microscopic plants produce most of the oxygen that comes from the sea. The exact causes of this decline are unknown, but rising temperatures are suspect. Ocean oxygen production is now likely about one-third of historical levels. In 2050, just as the world's population is projected to hit a peak of nine billion people, phytoplankton will be down to 22 percent of historical averages.

CENSUS OF MARINE LIFE E&O

The Oceans Future project, one of the Census's 14 field assessments, suggests that 90 percent of the big fish are gone from the world's oceans—victims primarily of overfishing. While declining large fish stocks mean less oxygen consumption, the little fish and squid that replace them require even more oxygen. The best news from the Census is that a careful review of historical trends by its Oceans Past project shows that when species and ecosystems are protected, they do recover, albeit more slowly than many had hoped.

The Census was a global program funded from 2000 to 2010 by the Alfred P. Sloan Foundation to explore oceans from the shorelines to the deep sea basins to the polar oceans. It used libraries to search as far back as 1000 C.E., online databases to store 33 million records of where species lived, and modelers to predict the future. The Census itself uncovered a host of weird and wonderful creatures and ecosystems. Its purpose was to go where no one had ever been and see what no one had ever seen.

The disturbing truth is that humans are having unrecognized impacts on every part of the ocean, and there is much we have not seen that will disappear before we ever get a chance. Effective policy changes must move forward through all the global agencies that share authority over the open ocean. If healthy oceans teeming with phytoplankton return, we will all breathe a little easier.

PROTECT AND DEFEND

The last decade has seen an increasing number of Marine Protected Areas (MPAs). Australia led the way with its Great Barrier Reef Park, followed by large MPAs in the Northwestern Hawaiian Islands and Phoenix Islands in the Pacific. The Chagos Archipelago in the British Indian Ocean Territory is currently the largest MPA at 210,000 square miles, and the United States' Mariana Trench, just to the east of the Mariana Islands, an American protectorate in the Western Pacific, is the deepest at 36,000 feet. These are all territorial waters. Marine Census results have also been used to establish MPAs in the open ocean for unique habitats like seamounts—mountains that rise from the ocean floor but do not reach the surface where they'd become islands. Still, the mechanisms under the UN Law of the Sea Convention for protecting the open ocean have proved cumbersome and difficult to enforce. They are unlikely to prevent companies from mining gold or drilling for oil outside territorial limits. Although there is still no formal plan for a Census 2020, Census participants continue to work toward open water conservation goals. Society still has much to learn about protecting diversity in the 70 percent of the planet that is underwater.

Take the poor little copepod. With more than 2,500 species documented in the Census, they are typically about one-eighth of an inch in length with a teardrop-shaped body, long antennas, and

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an armored coating that is so thin as to be almost transparent. Marine scientists have documented a northward shift of scrawny tropical copepods, replacing fat, juicy Arctic copepods in the Norwegian Svalbard Islands. This shift is starving thousands of chicks of the numerous types of seabirds that nest there and depend on the disappearing fat species.

Additionally, the decreasing amount of permanent ice is transforming whole ecosystems, especially in shallow water. Until recently, permanent ice stabilized nearshore ecosystems. But now with more ice melting every summer, long-term residents are being replaced by fast multiplying transients. The Census's Antarctic Ocean project discovered a huge multiyear invasion of deep-water species replacing traditional ones when an ice shelf the size of Rhode Island broke away.

There is a close, yet little-known link between ice and oxygen. Twenty million years ago, the last time the earth was this warm, global ice was at a minimum. Below a thousand feet or so, where surface winds were no longer able to stir oxygen down from the surface, the ocean was essentially oxygen-free. When ice started to reform in the Antarctic, it created a way for oxygen to reach the bottom of the sea. When ice freezes, it creates a concentrated brine that is much denser than ordinary seawater. It is also highly oxygenated, because gases, particularly oxygen, dissolve best in cold water. This happens to be why we like cold carbonated drinks. The Census demonstrated the solubility phenomenon by revealing that all deep-sea octopuses south of the Equator came from a common Antarctic ancestor. As torrents of brine streamed from new Antarctic ice, salty lakes of oxygen rich water formed in the deepest ocean basins. The octopuses simply followed the oxygen, colonized individual salt lakes, and ultimately evolved into separate species.

Eventually, this freezing process filled the deep ocean with oxygen. Fish and every other marine creature that requires oxygen adapted to the deep sea, and we arrived at the ocean we know today. One consequence of global warming will be to turn off the icy brine pumps. If the deep ocean again becomes an oxygen-deprived zone, we may wind up with more ocean oxygen in the atmosphere. But, there will be a great deal fewer fish and octopuses to eat.

EVENTUALLY, THE MICROBES WILL TAKE THEIR REVENGE.

EL NIÑO AND GIANT BACTERIA

Off the Pacific coast of South America, Census scientists noticed drastic changes to ecosystems during El Niño years, when surface ocean waters are unusually warm. The normal ecosystems disappeared and were replaced by forests of giant bacteria. It turns out that El Niño pushes the zone of water where there is minimal oxygen up against the steep continental slope of South America. In these conditions, primitive anaerobic bacteria thrive, pushing out the normal inhabitants. The giant colonial bacteria can grow up to four inches long, becoming the trees of a marine forest with hundreds of other types of smaller bacteria. This bacteria forest can be hundreds of feet deep and run all the way from the southern tip of Chile to Panama.

When the oxygen minimum zone (OMZ) withdraws during La Niña, when surface ocean temperatures are

cooler than average, the forests vanish. Some bacteria, however, can survive in what's left of the OMZ and play the game repeatedly. OMZs in every ocean basin are currently increasing in volume. Eventually, the microbes will take their revenge. Census scientists estimate there may be a billion different kinds of this primitive bacteria, some of which have been around for a billion years or more just waiting to take back their lost oxygen-free territory and choke out the marine life like swordfish and tuna that require oxygen-rich environments.

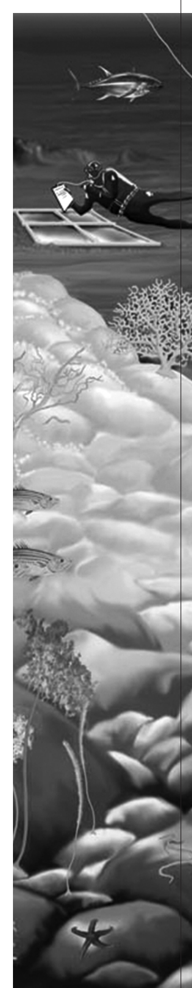
The Census's Coral Reefs project suggests another, even darker side of global warming. Increased carbon dioxide in the atmosphere causes heat retention, but it also dissolves in the ocean where it causes ocean acidification. Coral reefs are made of calcium carbonate and do well when oceans are well above neutral acidity but start to deteriorate at or below neutral acidity. Since gases, including carbon dioxide, dissolve best in cold water, the Arctic and Antarctic will be the first to succumb. Confirming this, Census scientists recently stumbled upon a huge submerged coral reef off the north coast of Norway where the Gulf Stream keeps temperatures high enough for corals, which are typically tropical, to grow. Unfortunately, the surrounding cold water is dissolving large amounts of carbon dioxide. Consequently, scientists predict this entire reef will be dead by 2020.

Acidity is increasing more slowly in tropical regions where corals are common. Known as the "rain forests" of the ocean, corals are estimated to contain more than 30 percent of the ocean's total biodiversity. More than half are likely doomed by 2100.

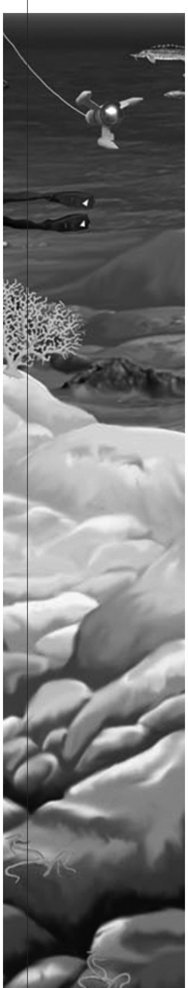
There are still more problems with acidic water in the vicinity of the South Pole. Swimming, tiny plankton-like snails called pteropods, or sea butterflies, represent a huge biomass in Antarctic waters and are a food source for hundreds of other species in that ecosystem. Unfortunately, their shells cannot develop in acidic water. The full consequences of their decline are not yet clear, but the entire ecosystem could be rapidly and severely damaged.

CENSUS POLICY

Throughout the term of the Census, protecting unique ocean habitats has proved challenging. Despite some noble words and promises from governments, there is little evidence that they have begun to grasp, let alone deal with, the challenges of global warming. Still, the Top Predators and Continental Shelves projects introduced some remarkable new animal tracking technologies that have allowed Census scientists to show beyond a shadow of doubt that animals use the Pacific basin in ways no one had previously imagined. Both initiatives resulted in policy changes to help restore endangered species, and their technologies are spreading to other oceans through ongoing projects like Tag-A-Giant in the Atlantic and the Ocean Tracking Network around the globe.



Top Predators focused on large animals that could carry tags linked via radio to several networks of orbiting satellites. It was the largest animal tagging study in history and showed that a large range of animals—including various birds, turtles, whales, tuna, and sharks—consider the entire Pacific basin home and move freely across it. The project reveals that while most of the ocean looks the same to humans, the critters that live below the surface have a very different view and tend to concentrate in certain "hot spots." The most direct analogy is land animals in Africa that appear to roam the plains at random until careful study reveals that all are traveling between fixed locations, usually their watering holes. Perhaps the biggest surprise uncovered by Top Predators is the migration, during certain seasons, of animals from every corner of the Pacific to the highly productive California Current system to feed. This has led to a series of policy efforts to increase the size of protected marine areas in this region, preserving a broad range of species in each of them.



The Continental Shelves project uses new technology to put uniquely coded tags in animals as small as three-quarter ounce baby salmon as they swim out to sea from the rivers where they hatched. These tags emit high frequency sounds above the hearing range of the animals and are recorded on lines of receivers placed strategically in locations the animals must cross. This monitoring allows calculations of where animals went and where they died—new information never before available.

A surprise policy consequence from this project came from a study of the river migrations of endangered green sturgeon by the Native American tribe that owned the fishing rights in California rivers. These uniquely coded tags showed up on receiver lines 650 miles away on the west coast of Vancouver Island in Canada. It turns out these endangered fish spend almost half their lives in an area where they risk being captured in fishermen's trawler nets. Once this indisputable truth was known, the Canadian Department of Fisheries and Oceans was able to close trawling operations seasonally when sturgeon were present. The good news is that this may have averted an international incident. During discussions with the scientist who tagged the fish in California, the question arose whether these were Canadian or American fish. His immediate response was, "They are Indian fish and always have been. We don't even recognize that border."

Such tracking, using coded-tag technologies put in place by the Ocean Tracking Network with Canadian government underwriting, has demonstrated the enormous value of collecting hard evidence of changes in marine animal behavior. The goal is to generate a global network of compatible tagging systems and tools that monitor changing oceanographic conditions below the few centimeters that can be monitored from satellite imagery.

WITHOUT THE MARGINS PROJECT, RESEARCHERS NEVER WOULD HAVE FOUND THE VAST RESERVES OF METHANE HYDRATES OR THE CURIOUS ICEWORMS THAT OCCUPY THEM.

The UN Global Ocean Observing System and partner institutions have responsibility for maintaining the equipment and collecting records of tagged animals that pass over receiver lines similar to those developed for the Census Continental Shelves project. The sound-based tags are significantly cheaper than satellite tags, and for larger creatures like sturgeon, they can be battery-powered to provide continuous monitoring of behavior changes for over a decade—the timescale of global warming.

The system is not yet fully deployed but can already be found off the Canadian, American, Australian, and South African coasts. Though trans-oceanic records from sound tags cannot yet compete with satellite tags, the Global Ocean Observing System's collaboration with Tag-A-Giant has monitored blue fin tuna moving between Canada and the Gulf of Mexico. When the receiver line across the Strait of Gibraltar is completed this year, blue fin tagged in North America are expected to show up there. The Atlantic blue fin stocks were recently proposed as candidates for protection under the Convention on Trade in Endangered Species of Wild Fauna and Flora but have not yet been listed. More information on movement and migrations will encourage conservation of this iconic species.

IMPACT

The Near Shore and Continental Margins projects each carry enormous future policy implications. The Near Shore project uses the simplest technology—a scuba diver descending no more than 30 feet—while Continental Margins uses the most sophisticated equipment, relying on an array of submarines traveling to the deep sea floor at depths of 9,000 to 18,000 feet.

The Near Shore project focuses on the ocean that people see and fish everyday. The project is quite charming in its easy-to-understand approach. Researchers wrote protocols to document the diversity between the high tide mark and 30 foot depth, often requiring nothing more complicated than one and two yard squares to count species. The rules are so simple that a child can follow them—and often do. Many universities, even high schools, have adopted the protocols to teach students about biodiversity—a perfect way to monitor change in the Near Shore and determine whether that change reflects climate change or invading species. If some new creature appears, it can be dropped in a vial of alcohol and sent off to be DNA bar coded. Recognizing the beauty of this simplicity, Japan has agreed to fund repeated Near Shore surveys every five years for the next century to understand how climate is affecting ocean diversity. The UN Environment Program is recommending similar actions globally.

In contrast, the Continental Margins project deals with a region that is rich in resources but largely unknown to humanity. For many nations, the margins in question are within their exclusive economic zones where oil, gas hydrates, and precious metals are under national control. This aspect of the Marine Census has uncovered resources these nations own but were unaware of. Most of the margins included in the study had seen surprisingly little exploration, in part because the technologies for working down to such depths, so close to rocky outcrops, were only recently developed. The Margins project has already discovered an amazing assortment of new species and ecosystems, which had been ignored in the search for resources at even greater depths. Without the Margins project, researchers never would have found the vast reserves of methane hydrates or the curious iceworms that occupy them. *Hesiocaeca methanicola* is a pink polychaete, or bristle worm, one to two inches long that lives on the methane ice that forms at great depths under high pressure and at low temperatures. It eats the bacteria that feed on the methane. When brought to the surface, this ice starts to melt, and it can be lit with a match. Although methane hydrates are potentially a rich source of energy, they are also a danger to the diversity along the margins. As deep waters warm, the ice melts, and it can cause huge underwater landslides that destroy unique habitats.

Many Census field projects amassed a wealth of information on species distributions. The Ocean Biogeographic Information System (OBIS) was created to capture this information and to integrate the data across all scientific disciplines. Combined with data contributed through a series of regional and thematic studies, OBIS now has records of over 33 million species drawn from over 1,000 individual sets of data. By its very nature, OBIS integrates data from all oceans, marine habitats, and types of organisms, enabling research and analysis of an unprecedented scale and scope. In this fashion, it can look more easily at the global picture, beyond the details of individual studies.

Obviously, there are large biases in OBIS data holdings, as larger, charismatic species are much better represented in the OBIS holdings. All marine mammals and turtles known to exist are represented in OBIS. But for less conspicuous organisms, there are believed to be large numbers of species without a single observation. It's also quite clear that the vast majority of our observations take place at the surface and in shallow waters. While we have some records at the bottom—especially the deepest oceans—we lack a broad spectrum of observations in the deep mid-waters. OBIS proves its worth by helping us quantify the unknown and assist us in setting priorities for future research agendas.

Several Census projects explored the mid-ocean depths but the most intense was the Mid-Atlantic Ridge project. In its early days, this program sent one of the Russian MIR deep submersibles, capable of operating below 19,000 feet, to the bottom of the Charlie-Gibbs Fracture Zone, a stretch of 1,500 miles where high velocity currents flow through the deepest canyon of the underwater mountain range that runs from the Arctic to the Antarctic. Despite the amazing views of nature's mysteries out the window, the observer barely had room to turn over and could only relieve himself by peeing into a can. Not exactly luxury accommodation for a trip that took 16 hours. One of the most surprising discoveries in the mid-waters was a new family of bigfin squid over 20 feet long. These squid turned out to be distributed globally but have still never been caught at the half-mile depth where they are common. The squid's larvae have been collected and DNA bar coded near the surface, but the big ones always escape, speeding away faster than any net can be towed.

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The floor of this region also revealed new mysteries. A strange pattern seen on the sandy bottom where the MIR landed eventually proved to be produced by an enteropneust. Although it looked like a big red worm digesting food from the sand that passed through its gut, it turned out to be more closely related to humans and other vertebrates than to worms. With the discovery of dorsal and ventral nerve cords, it has now been described as a completely new family of organisms as well as a new genus and species. Ancient animals still survive unchallenged in these timeless habitats at the bottom of the sea. The Census project led to the declaration of the Charlie-Gibbs Fracture Zone as a 56,000 square mile Marine Protected Area (MPA) under the Convention for the Protection of the Marine Environment of the North-East Atlantic, known as the OSPAR Convention—the world's largest deep-water MPA.

Notwithstanding its known biases and shortcomings, OBIS data is contributing to the management of the environment, mainly through collaborations with the Convention on Biological Diversity and the Food and Agricultural Organization of the United Nations. After the end of the first Census in 2010, the Intergovernmental Oceanographic Commission of UNESCO adopted OBIS as one of its functions. This is a promising platform for OBIS to inform international organizations about the state of marine biodiversity.

Still, unless we find a wealthy donor committed to holding these projects together, they appear doomed to drift apart, some disappearing completely. The Census proves how crucial it is to use the array of technologies it helped create to monitor the rapid changes in ocean ecosystems as part of an effort to manage and protect them. It would be logical to report on changes again in 2020, but funding is drying up. The Census showed us the vast scale of unknowns in the ocean, and most frightening, it made clear that thousands of species we have never even seen are disappearing—an immediate, and little-appreciated consequence of global warming and ocean acidification.

The Census estimates that three-quarters of all ocean species are still unknown, and a high proportion of these are hidden deep in the ocean, which remains expensive to sample. Society must quickly develop the will to fund ocean exploration at a level that could ultimately put to rest the longstanding truth that we know more about the moon's backside than we do the ocean's bottom. It is hard to protect species that have not been shown to exist. ●