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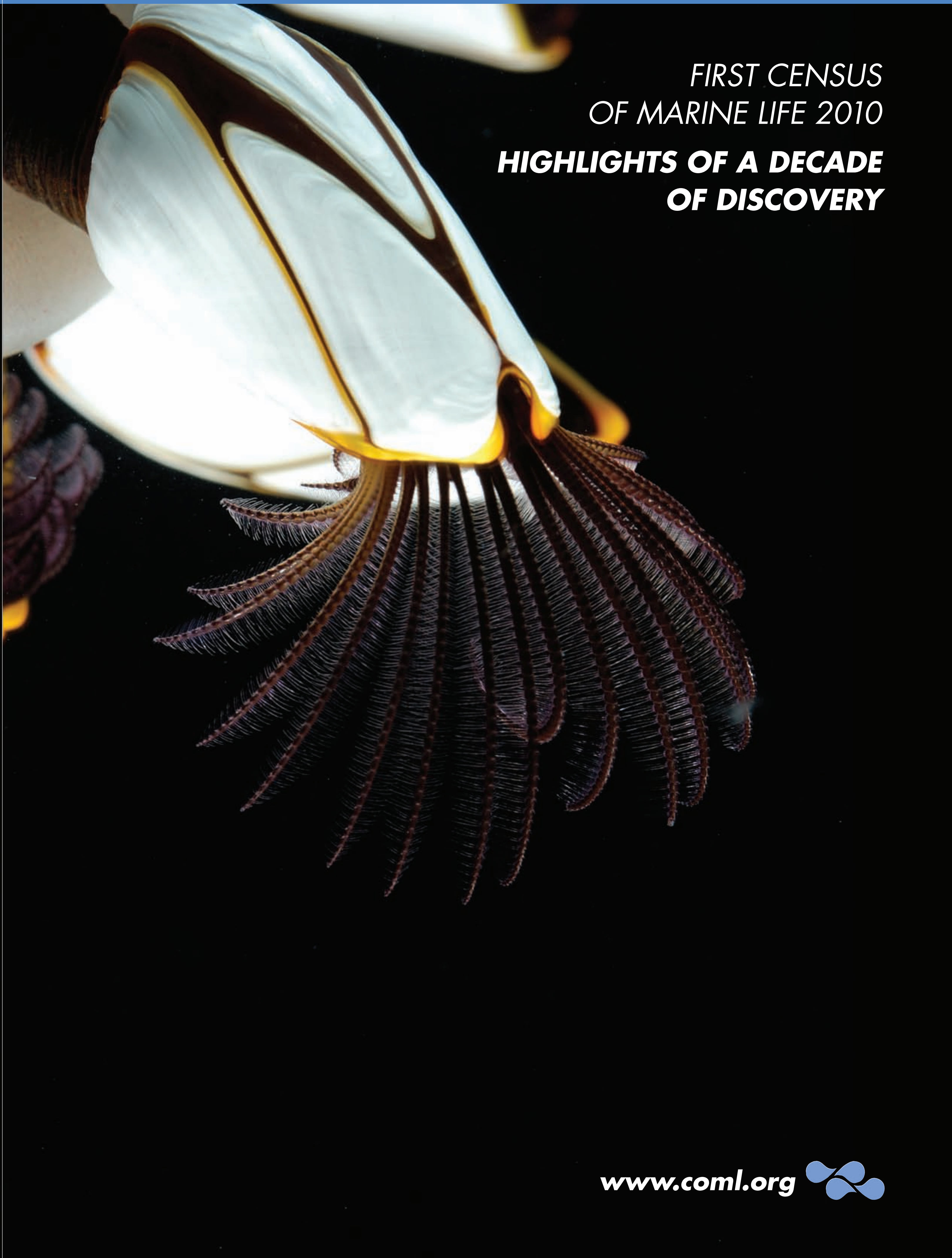

FIRST CENSUS OF MARINE LIFE 2010

HIGHLIGHTS OF A DECADE OF DISCOVERY

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We thank the thousands of scientists and hundreds of sponsors who made possible the First Census of Marine Life. We hope it will stimulate science, engage the public, and inform management for decades to come.

Ian Poiner, Chair
International Scientific Steering Committee
Census of Marine Life

A school of sardines off Port St. Johns, South Africa, 2005.
Image: Julien Sarano, Galatée Films

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CONTENTS

Readers may approach this volume, like marine life, at different levels. A sequence of images and blue captions tell the story, as does the black text, and the combination.

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from around the globe

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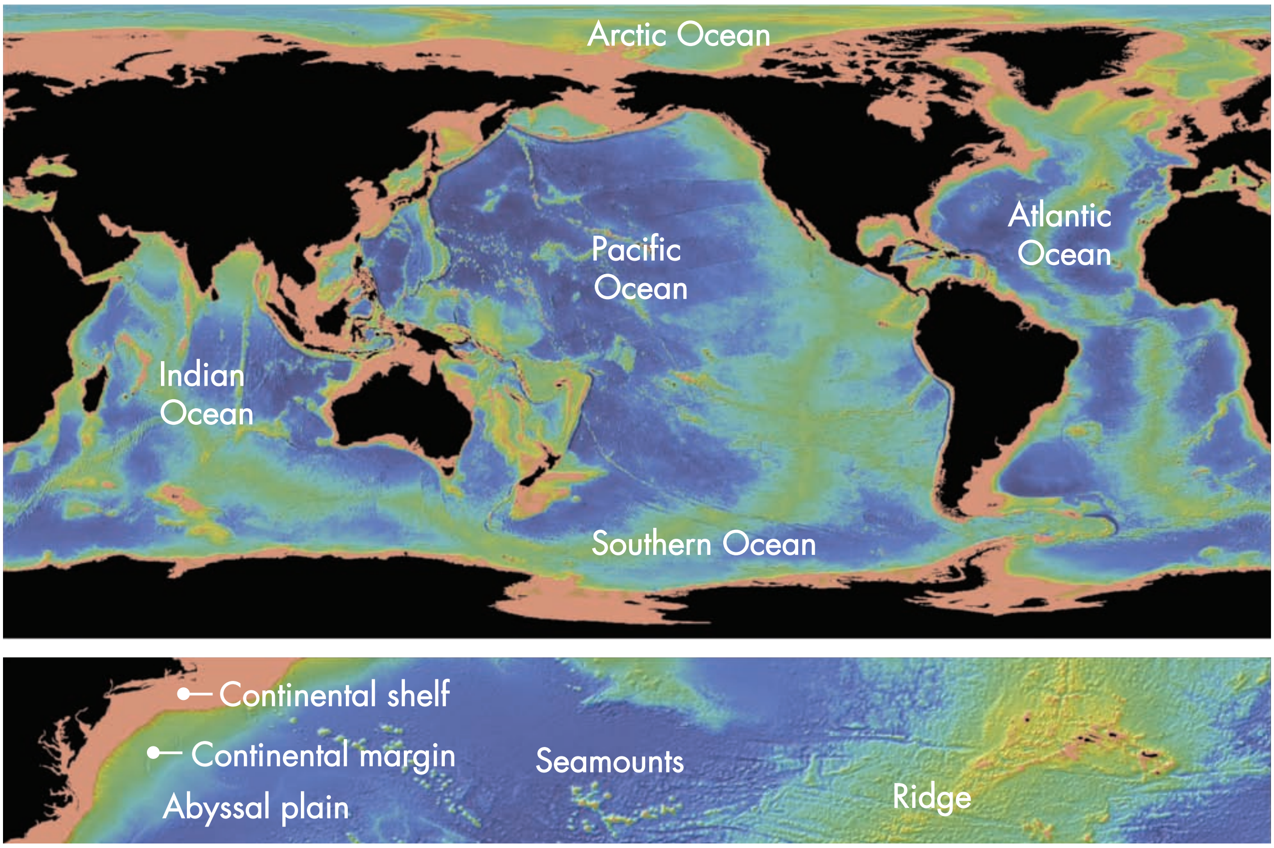
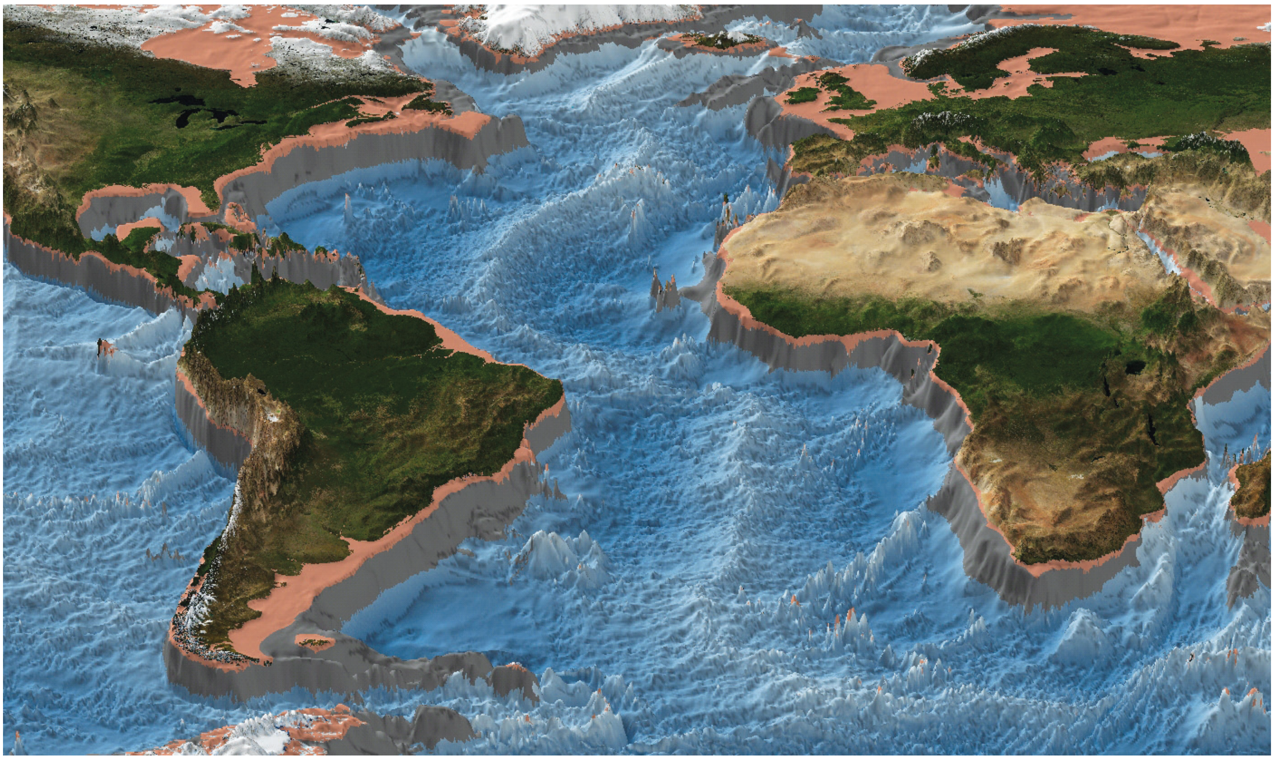


1. The oceans encompass almost 10 times as much deep sea (averaging 4,000 meters) as shallow shelf (up to 200 meters). Shelves may be as narrow as 5 kilometers (e.g., off California or Chile) or as wide as hundreds of kilometers (e.g., off China or Argentina). Until recently, most human activities, and their impacts, have concentrated on the shallow shelves highlighted in pink around land here. The largest oceans are the Pacific and the Southern, which whirls like a carousel around Antarctica. Earth's Southern Hemisphere is 80 percent water, mostly very deep. Undersea mountain ranges or ridges divide ocean basins, and about 100,000 seamounts higher than 1,000 meters rise from the seafloor.
Image: Census of Marine Life Mapping and Visualization Team



2. Between the shallow pink shelves that extend to a depth of about 200 meters around continents and the blue abyssal plains beneath the deep sea that average about 4,000 meters deep, the gray continental margins slope downward. Their gradient, exaggerated in this rendering, brings great and little-explored biodiversity. The margins also offer access to vast resources of petroleum and natural gas. In the view here, the world's longest mountain range, the Mid-Atlantic Ridge, traverses the ocean from north to south.
Image: Census of Marine Life Mapping and Visualization Team

RESANSMAN LAVI MAREN

SUMMARY

In the late 1990s, leading marine scientists shared their concerns that humanity's understanding of what lives in the oceans lagged far behind our desire and need to know. Some emphasized the question, "What kinds of life inhabit the oceans?" They pointed to opportunities to discover new kinds of life and to catalog and estimate the total diversity of life in the vast global ocean. Others asked, "What lives where?" They highlighted establishing addresses of marine life and drawing reliable maps of neighborhoods and travels. Still others asked, "How much of each lives?" and pointed to the human appetite for seafood. Everyone worried about changes in marine life and the need to improve management with sound knowledge.

In the year 2000, the scientists founding the Census of Marine Life converged on a strategy, a worldwide Census to assess and explain the diversity, distribution, and abundance of marine life. The founders organized the Census around three grand questions: What did live in the oceans? What does live in the oceans? What will live in the oceans? They designed a program to explore the limits to knowledge of marine life. They agreed to report in the year 2010.

Delving in archives, setting out on more than 540 expeditions in all ocean realms, and partnering with other organizations and programs, the 2,700 scientists from more than 80 nations who have become the Census community have assembled, augmented, and organized what is known about life in the oceans. They have drawn baselines for measuring changes of marine life after natural changes and human actions. Equally important, the Census has systematically delineated for the first time the unknown ocean.

Many books, papers, Web sites, videos, films, maps, and databases now form and report the Census. The pages here highlight its findings, describe its legacies, and tell how it worked.

Diversity

The Census encountered an unanticipated riot of species, which are the currency of diversity. It upped the estimate of known marine species from about 230,000 to nearly 250,000. Among the millions of specimens collected in both familiar and seldom-explored waters, the Census found more than 6,000 potentially new species and completed formal descriptions of more than 1,200 of them. It found that rare species are common.

With its collective digital archive grown to almost 30 million observations, the Census compiled the first regional and global comparisons of marine species diversity. It helped to create the first comprehensive list of the known marine species, already passing 190,000 in September 2010, and also helped to compose Web pages for more than 80,000 of them in the Encyclopedia of Life.

Applying genetic analysis on an unprecedented scale to a dataset of 35,000 species from widely differing major groupings of marine life, the Census graphed the proximity and distance of relations among distinct species, painting a new picture of the genetic structure of marine diversity. With the genetic analysis often called barcoding, the Census sometimes shrank seeming diversity by revealing that organisms had been mistakenly called separate, but generally its analyses expanded the number of species—and especially the number of kinds of different microbes, including bacteria and archaea.

After all its work, the Census still could not reliably estimate the total number of species, the kinds of life, known and unknown, in the ocean. It could logically extrapolate to at least a million kinds of marine life that earn the rank of species and to tens or even hundreds of millions of kinds of microbes.

Distribution

The Census found living creatures everywhere it looked, even where heat would melt lead, seawater froze to ice, and light and oxygen were lacking. It expanded known habitats and ranges in which life is known to exist. It found that in marine habitats, extreme is normal.

With sound, satellites, and electronics, sometimes carried by marine life itself, the Census tracking of thousands of animals mapped migratory routes of scores of species and charted their meeting places and blue highways across the interconnected ocean. The tracking measured animals' surroundings as they swam and dove and revealed where they succeed and where they die. The Census found temperature zones favored by animals and saw the immigration into new conditions such as melting ice.

Now anyone can see the distribution of a species by entering its name at iobis.org, a Web site that accesses the names and "addresses" of species compiled in the Census's global marine life database.

With the names and addresses of species compiled in the database, the Census found and mapped the places of high and low diversity of marine life, globally. Coastal species showed maximum diversity in the tropical Western Pacific, whereas high diversity of species frequenting the open ocean peaked across broad mid-latitudinal bands in all oceans. In deep water and on the deep-sea floor, the Census discovered patterns of life on ridges, seamounts, abyssal plains, and the margins of continents and defined new provinces and classifications.

The same Census data reveal where explorers have not yet looked, the unknown ocean. For more than 20 percent of the ocean's volume, the Census database still has no records at all, and for vast areas very few.

Abundance

After establishing historical baselines from sightings, catches, and even restaurant menus, the Census documented declining numbers and sizes, too, even within a human generation. In enough cases to encourage conservation, the Census documented the recovery of some species. History shows people began catching marine life long ago, and their extractions are far broader in scope than once thought. Historically, overfishing and habitat destruction lead the ranking of threats to marine life associated with human activities.

With sound, the Census observed tens of millions of fishes assembling swiftly and swimming in coordinated schools as large as Manhattan island, and also saw hosts of animals commuting at regular hours, moving back and forth to the surface from hundreds of meters below.

The Census affirmed that by weight most marine life is microbial, up to 90 percent. The weight of Earth's marine microbes equaled about 35 elephants for every living person.

Analyzing indirect observations from oceangoing vessels since 1899, Census researchers discovered that the food-producing phytoplankton near the surface has declined, globally. The Census maps of the global seafloor showed that the delivery of food in a "snow" from water above controlled the mass of living things on the floor. On the seafloor, the quantity of life peaks toward polar regions, along continental margins where cool currents well up toward the surface, and where equatorial currents diverge. On the deep-sea margins, the Census unexpectedly discovered mats of bacteria and reefs of coral extending hundreds of kilometers.

While patchy evidence from the phytoplankton near the bottom of the food chain and more extensive evidence from large animals at the top of the food chain suggest decline, whether the total weight of life in the ocean is changing remains unknown.

Legacies

At the end of its decade, the Census bequeaths legacies of knowledge, technology, and work habits.

Regarding knowledge, the Census recorded its findings in more than 2,600 papers, many freely accessible online. The Census built the largest repository of data about marine species by compiling observations and adding its own, and then made it a publicly accessible infrastructure for future research, which governments have committed to sustain. The Census drew baselines to help nations and the international Convention on Biological Diversity select areas and strategies for greater protection of marine life. Its baselines will help assess habitat changes such as warming water or damage from oil spills.

Regarding technology, the Census proved new technology, such as DNA barcoding for the identification of marine life. It arrayed microphones from California past Canada to Alaska to pioneer a global ocean tracking network for animals, invented Autonomous Reef Monitoring Structures to standardize global assessment of reef life, and fostered acoustic systems to measure abundances over tens of thousands of square kilometers. Together, these technologies show that the incipient Global Ocean Observing System can observe life as well as water temperature and waves.

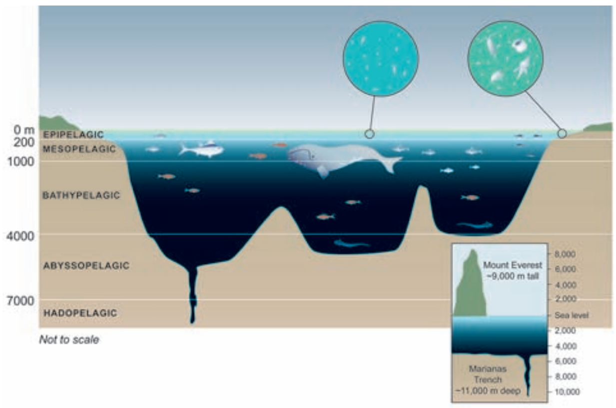
Regarding work habits, the Census brought scientists with different interests from different nations together under one umbrella, to use standard protocols for sampling marine life from the deep sea to the near shore, to speed the adoption of good techniques, to build capacity economically, and to jump start initiatives in marine research. It strengthened partnerships of scholars in the humanities and natural and social sciences to use archival research to build the picture of life in oceans past and assess changing diversity, distribution, and abundance.

As it worked, the Census found that the causes separating the known, unknown, and unknowable about marine life fall into five categories: the invisibility of the lost past, the vast expanse of the oceans, difficulties of assembling knowledge of parts into knowledge of a whole, blinders we put on ourselves by choosing not to learn or spend, and unpredictable disturbances such as tsunamis.

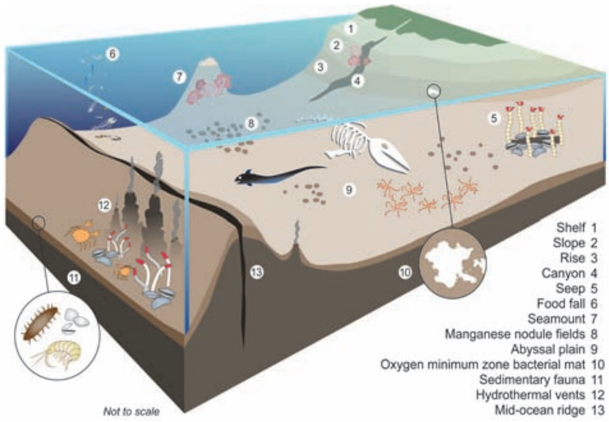
The Census showed that we know less about the small than the large and that generally knowledge is inversely related to size. But some patterns exceed our field of vision, and for these the Census devised "macroscopes," tools to make sense of very large regions or datasets, to overcome limits to knowledge.

The Census encountered an ocean growing more crowded with commerce and transparent through technology. Setting out to draw baselines of the diversity, distribution, and abundance of species, the first Census of Marine Life documented a changing ocean, richer in diversity, more connected through distribution and movements, more impacted by humans, and yet less explored than we had known. The Census has multiplied the qualified experts, developed and spread technologies for discovery and monitoring, improved access to data, and informed decisions about conserving marine species and regions. The legacies of the Census—the baselines of knowledge, the cascade of new technology, the collaboration across borders—promise more benefits for humanity and the oceans.

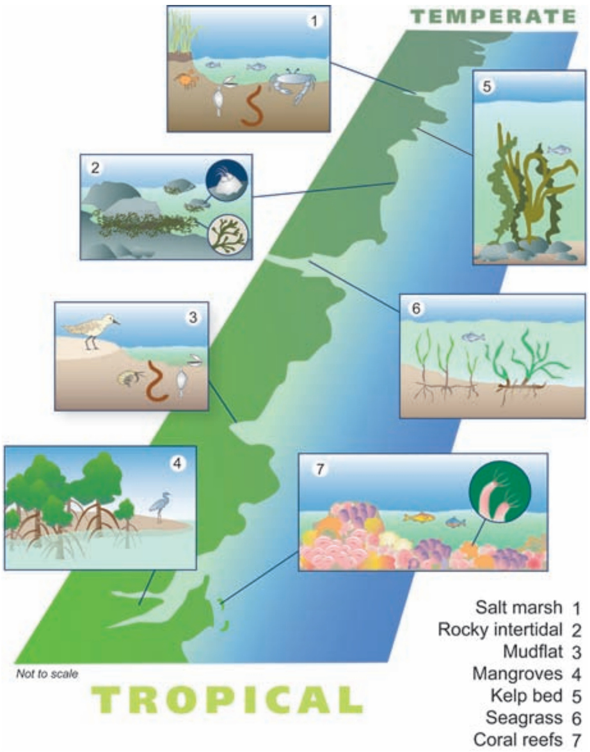
Marine habitats



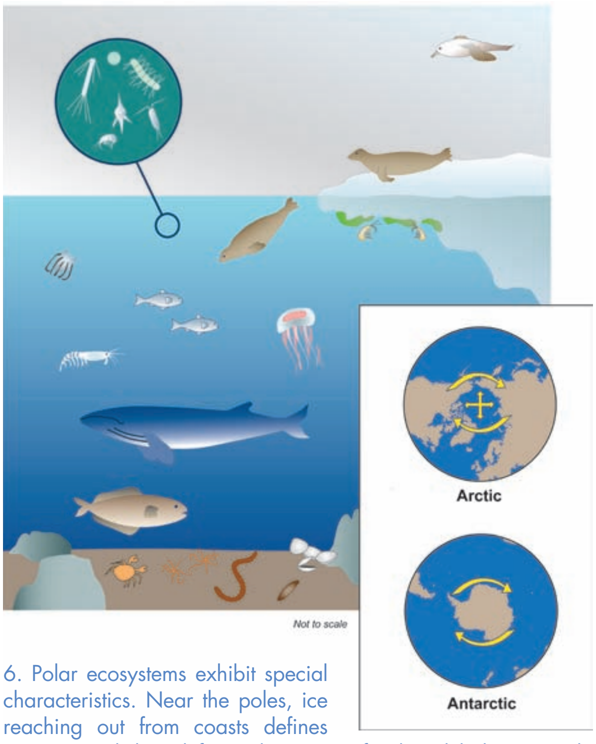
3. In "pelagic" or open ocean ecosystems, differences in light, temperature, salinity, and nutrients determine productivity. Productivity, in turn, limits what kinds of creatures can live there. The prefixes to pelagic in the left of the figure refer to depth zones. *Image: Lianne Dunn*



4. An array of specialized habitats exists on the deep-sea floor, thousands of meters below the surface. The Census standardized datasets to enable comparisons of kinds of life among these specialized habitats. *Image: Lianne Dunn*



5. The Census studied many different coastal habitats from the tropics near the equator up to temperate environments at midlatitudes. Each habitat has unique characteristics and its own suite of species. *Image: Lianne Dunn*



6. Polar ecosystems exhibit special characteristics. Near the poles, ice reaching out from coasts defines seasons and thus defines changes in food and habitat. Land surrounds the waters of the Arctic Ocean, whereas the water of the Southern Ocean surrounds Antarctic land. *Image: Lianne Dunn*

INTRODUCTION

Beginning as it did with the origins of humanity, our use of the oceans proceeded for millennia with a knowledge of ocean life only along coasts and on the surfaces where our boats dared to venture. Visits to new and deeper waters regularly revealed unexpected and unfamiliar life. Now, detailed navigational and seafloor charts and accurate storm forecasts demonstrate growing knowledge of the physical ocean and marine life continues to surprise us. In Australia, explorers encountered a shrimp thought to have gone extinct 50 million years ago. Off Africa's Mauretanian coast, they found relics of cold-water corals extending over 400 kilometers in waters 500 meters deep in one of the world's longest reefs. Near Chile, they found giant mats of microbes covering an area of seafloor about the size of Greece or Nicaragua.

As astonishing discoveries continue and even increase, the oceans grow more crowded and transparent. Along shores, our cities, ports, aquaculture, and windmills increase. Farther offshore, our oil wells, shipping, fisheries, cables, and soon perhaps deep-sea mining spread. The different uses interact, as when shipping ports displace fishing harbors, and oil becomes a greenhouse gas in the atmosphere that acidifies and warms the oceans. Meanwhile, divers and submarines as well as robotic ears and eyes, some carried by animals themselves, render even the dark, deep waters transparent for humans. The crowding requires, and transparency enables, more exploration of marine life to buoy wise policies.

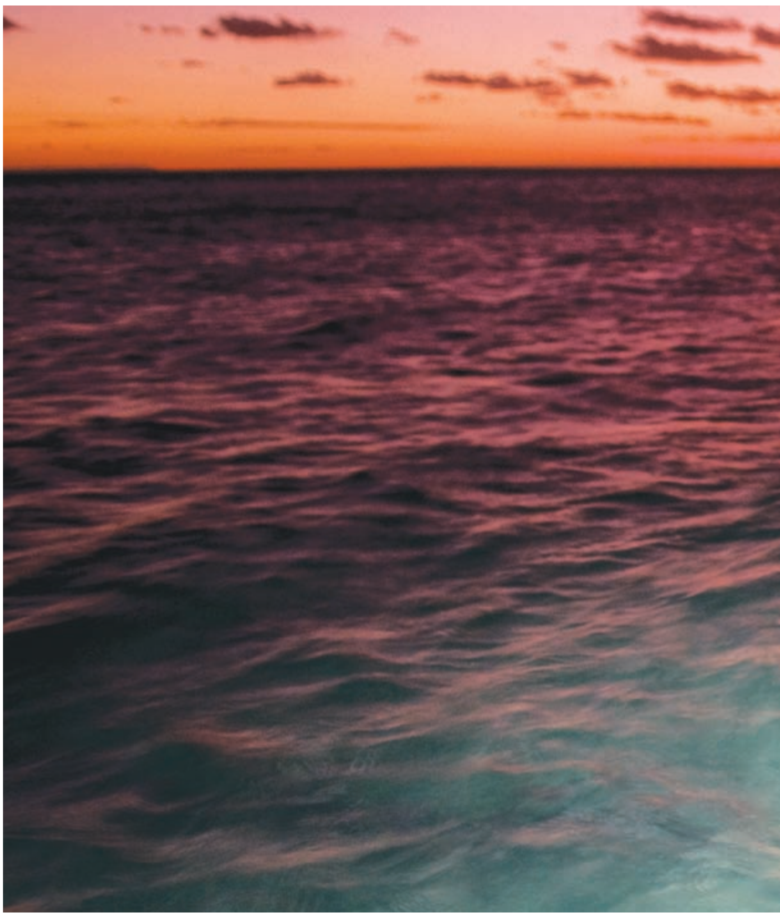
Thus in the year 2000, the Census of Marine Life began its decade-long exploration of life in the global ocean. It sought to assemble and better organize the known, shrink the unknown, and specify what will be very hard to know or even unknowable. Its strategic categories were learning the diversity, distribution, and abundance of marine life from microbes to whales. It engaged thousands of scientists from all continents on hundreds of expeditions and invested hundreds of millions of dollars. It employed divers, nets, submersible vehicles, genetic identification, sonars, electronic and acoustic tagging, listening posts, and communicating satellites. The Census spanned all oceanic realms, from coasts down slopes to the abyss, from the North Pole across tropics to the shores of Antarctica. It followed flying seabirds and collected cores from the seafloor. It ranged from the long past to the future. It systematically compiled information from new discoveries and historical archives and made it freely accessible. Census explorers found life wherever they looked, a riot of species.

This collection of highlights tells who took the Census and lessons from their collaboration during joint explorations and efforts around the world. First, it answers readers' questions about life in the global oceans from the store of knowledge about the oceans, especially new knowledge added to the store during the fruitful decade of the Census.

Overcoming limits to knowledge

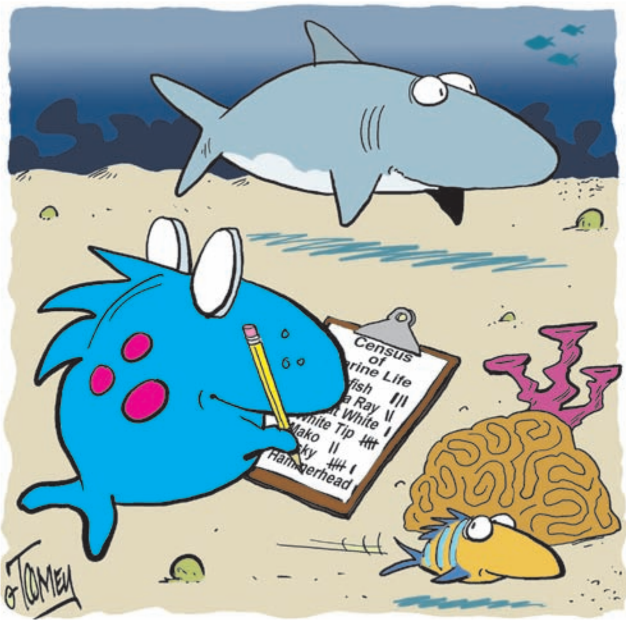
Calling Earth by the name Planet Ocean helps to understand the span of knowledge of the seas stretching around the globe. Humanity is a species that breathes air, which focuses our eyes and lives on Planet Earth. We might better call a globe covered 70 percent by water Planet Ocean, as did Arthur C. Clarke, science fiction author and conceiver of the communications satellite. In fact, more than 80 percent of Earth's Southern Hemisphere is ocean, and 70 percent of the entire ocean is an abyss with a floor averaging 4,000 meters below the sea surface and descending to 10,924 meters at the deepest point. Apart from microbes living in rocks, 99 percent of Earth's biosphere is in or under marine waters. At the outset of the Census, oceanographers estimated that only 5 percent of the ocean had been systematically explored for life.

Faced with a vast unknown, the Census adopted a deliberate strategy to understand the limits to knowledge. Some limits separate the known from the unknown. Experience teaches that money, organization, work, and time can often move unknowns into the province of the known. As the Census steadily discovered new kinds of life, learned where species lived and traveled, and count-



7. Image: Gary Cranitch

ed or weighed the species, it shrank the unknown and enlarged the known. Beyond the unknown and across a dark boundary lies the unknowable about marine life. Wonders of the Internet, submersible vehicles in the deep, and genetics that extract information from a single cell occasionally jump the boundary between unknown and unknowable. Still, much of what we would like to know about the oceans remains very hard to learn.

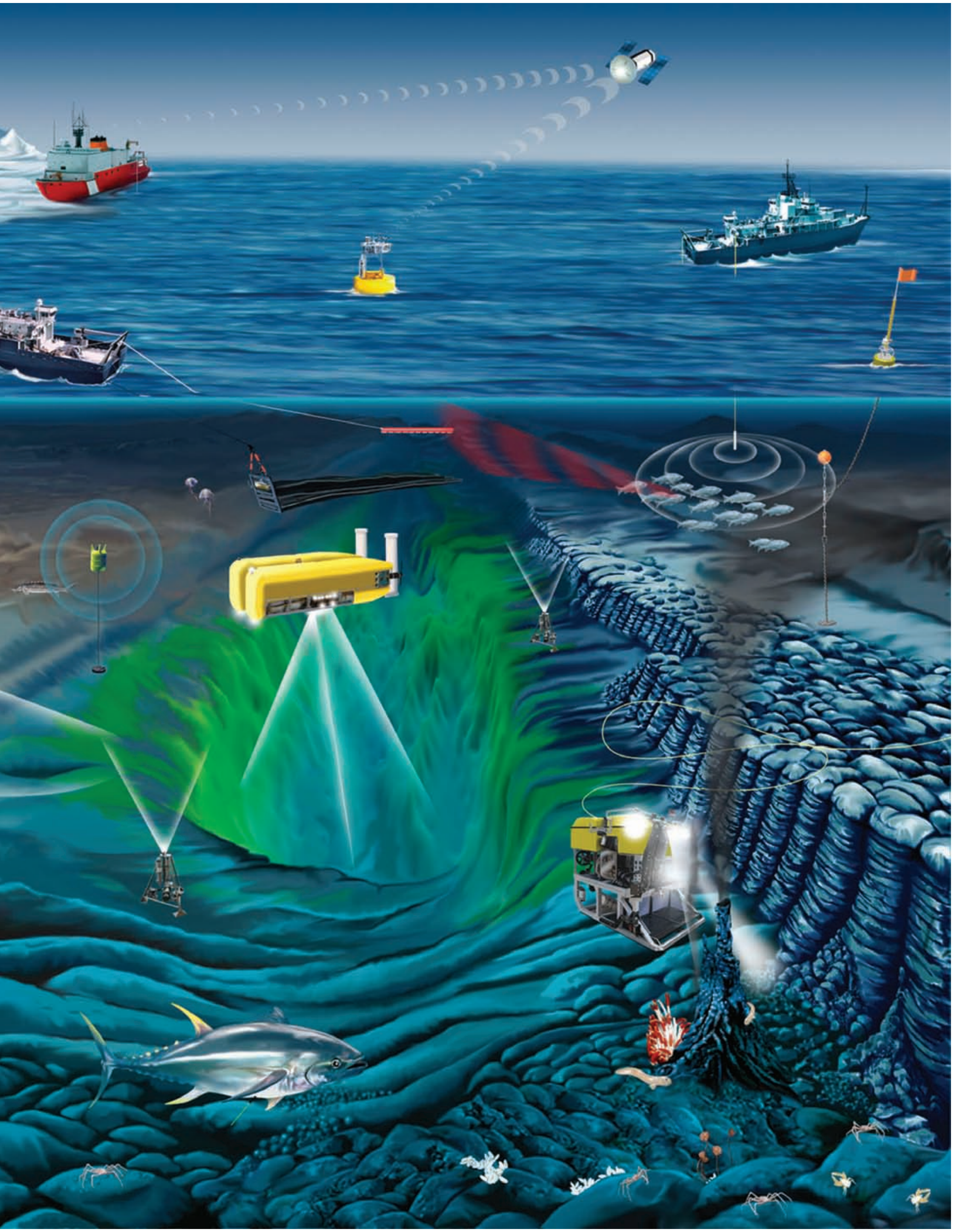


8. The idea of learning everything that lives in the sea plus their addresses and numbers brings smiles to people's faces. Cartoonist Jim Toomey imagined how sea animals might themselves conduct a Census of Marine Life. Fortunately, the opportunity for discovery and the scale of the Census also attracted thousands of scientists from more than 80 nations, who rallied around learning the diversity, distribution, and abundance of marine life in the past, present, and future. *Image: Jim Toomey*

In considering ocean life, the causes that separate the known, unknown, and unknowable are numerous and diverse but fall into five families: the invisibility of the lost past, the vast expanse of the oceans, difficulties of assembling knowledge of parts into knowledge of a whole, blinders we put on ourselves by choosing not to learn or spend, and unpredictable disturbances such as tsunamis. The loss of an archive or extinction of a species makes some of yesterday's marine life unknowable. The immense variety and rapid evolution of microbes may make some of today's marine life unknowable. A lack of experts may keep some kinds of tomorrow's life unknown if not unknowable.

As the Census studied neglected archives and encountered species thought to be extinct, arrayed listening posts for migrating salmon, and employed genetic barcoding to distinguish new species, it penetrated and jumped limits to knowledge. The Census deployed a fleet of new tools for exploration as well as traditional nets, quadrats to frame areas for sampling, and coring devices to retrieve seafloor mud and its residents. Perhaps most powerful was the collective database of the Census, a macroscope that allowed researchers to see patterns that before had been too large to see.

9. Census investigators explored on and beneath polar ice. Their aircraft remotely sensed animals through properties of scattered light. Marine animals themselves carried tags that stored records of their travels and dives and communicated with satellites. Fish carried tags that revealed their migration past acoustic listening lines. Sounds that echoed back to ships portrayed schools of fish assembling, swimming, and commuting up



and down. Standardized frames and structures dropped near shores and on reefs provided information for comparing diversity and abundance. Manned and unmanned undersea vehicles plus divers photographed sea floors and cliffs. Deep submersibles sniffed and videotaped smoking seafloor vents. And nets and dredges still caught specimens, shallow and deep, for closest study. *Image: E. Paul Oberlander*

10. *Image: Bodil Bluhm*

DIVERSITY

The number of different species of animals, plants, and fungi indicates biological diversity or biodiversity. Just as diversity is considered an attribute of security in financial investment, biologists often use biodiversity as a measure of the health of biological systems. Scientists may elaborate the simple definition of diversity as the number of species, and may calculate indices or zoom in to diversity of genes or out to diversity of the inhabitants of a region. Still, species typically serve as the common currency, and the inventory of species as the capital stock of biodiversity. Species stand at the base of the sequence of taxonomic groups or taxa and make up broader groups, first genus and then family, order, class, and phylum. The inclusive word taxa and its singular number taxon may mean any of the groups in the sequence.

Hence, to accomplish a biological census and compile the needed inventory in its first category, diversity, the Census focused on species. A common definition of species is that of a group of organisms capable of interbreeding and producing fertile offspring of both sexes (except in the case of asexually reproducing species), and separated from other such groups with which interbreeding does not normally happen. The Census compiled tens of millions of species-level observations obtained before and outside the Census and added millions of its own. It very likely discovered more than 6,000 new species and completed, for more than 1,200 of them, the formal descriptions meeting the high standards of the science of systematic biology. The Census even discovered a few species thought extinct. Census data on known and new species and the locations where they were reliably observed are recorded in the Ocean Biogeographic Information System (OBIS), an online, open-access, globally distributed network of systematic, ecological, and environmental information. The Census invented, constructed, and operated OBIS, demonstrating its power for mapping where species lived and traveled as well as graphing the number of described species, a number that rises toward the total number of living species and thus diversity of marine life. OBIS has grown past 28 million records, spanning 120,000 species assembled from nearly 1,000 datasets. Scientists have already analyzed the OBIS data to find global patterns of marine life, while OBIS adds 5 million records per year.

The Census also helped speed compilation of an unprecedented listing of all marine species ever described. The tally of the World Register of Marine Species, the authoritative and comprehensive online list of names of marine organisms, exceeds 190,000 names in early September 2010. And the Census partnered with the Encyclopedia of Life, an online reference source and database, to offer a Web page with vetted content for every marine species. Such pages, infinitely expansible, now cover more than 80,000 marine species. Neither of these online resources existed in 2000.

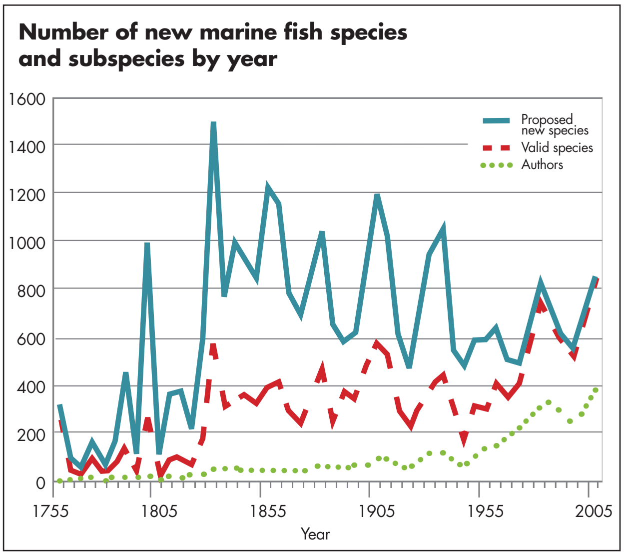
The continuing encounters with new species make it difficult to identify a single Age of Discovery for marine life. A timeline for marine fishes, probably the most studied sea life, shows at least eight peaks of discovery during the past 300 years. Peaks associate with scientific revolutions such as Linnaeus' binomial system for classifying species, great expeditions, heroic careers of individual experts, and technological advances that open new areas for exploration, including deep and cold regions. Increasingly aided by molecular biology and genetics, taxonomists are describing new marine species of fish alone at a rate reaching about 150 per year. Clearly the Age of Discovery continues for marine life, even for fishes, and diversity measured by the number of known species is expanding rather than shrinking.

Indeed, the total yearly addition to the number of all marine species has averaged about 1,650 since the Census began in the year 2000. While crustaceans (452 per year) and mollusks (379 per year) lead the way, the known sponges and echinoderms have been accumulating at yearly rates of 59 and 30, respectively. The best expert estimate of known marine species has risen from 230,000 early in the Census to at least 244,000 in 2010. Over the next few years, as old records are sorted out and new species described, the World Register should reach 250,000 kinds of marine life that have earned the rank of species.

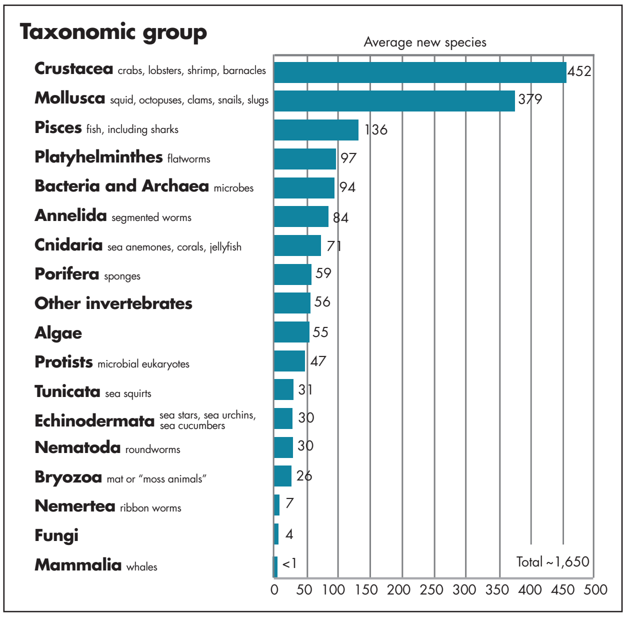
An optimist expects that eventually the total of all species will be found, and an extrapolation of the accumulating list of species holds a clue to what that total species and diversity will be. About 36,000 species of all kinds live in the well-explored European waters, and Census scientists anticipate that more than 40,000 marine European species exist, an addition of 10 percent. Because European waters are probably the world's best known, the proportion of species yet to be discovered may be higher elsewhere. In the Arctic, expected numbers of mollusk, arthropod, and echinoderm species exceed the present numbers by about 40 percent. The accumulating number of valid fish species in the oceans reached 16,754 in February 2010, leaving an estimated 5,000 more to be discovered.

Census researchers tried statistical methods to estimate how many forms of marine life remain to be discovered. Alas, or perhaps wonderfully, the eventual number remains unknown. The upward curve of accumulation of new species for most taxa and regions has yet to bend enough to calculate a firm plateau. Australian experts judged that the 33,000 known species in Australian waters amount to only 10–20 percent of estimated total species. Finding 1,200 species of crabs, about 7 percent of the total known global list of the group, in a few square meters of a single coral reef leads to speculation that reefs alone may provide habitat for 1 million to 2 million marine species.

When the Census began, its founders estimated that 1 million to 10 million marine species might exist. Expert judgment of Census scientists examining knowledge by region and taxa affirms that at least 1 million species of marine life likely exist, and thus at least three species



11. People often feel that everything must already be known, as discoveries grow and libraries accumulate. The continuing discovery of new fish species (and subspecies) demonstrates that the Age of Discovery is not over. The smaller number of species validated than proposed as new species illustrates the thorough evaluation needed before a species is declared truly new. The rising number of authors of species descriptions reflects the growing interest in marine biodiversity. *Source: William N. Eschmeyer and colleagues, 2010.*



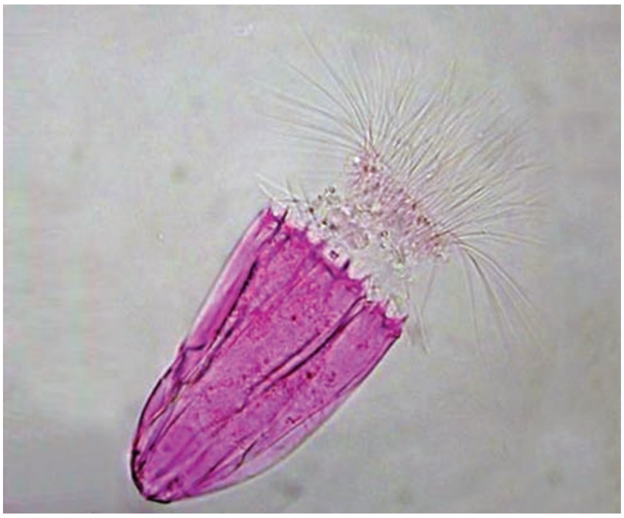
12. An average of about 1,650 new marine species were described each year between 2002 and 2006. Although the numbers of new Mollusca and Crustacea are highest, an average of 156 new species in the well-studied Pisces or fish group astonishes even Census researchers. Census researchers both collected specimens that might be new species and helped collate data worldwide about newly described marine species, including many described from specimens collected before the Census began or on expeditions not flying the Census flag. *Source: Philippe Bouchet and Benoit Fontaine.*

remain to be discovered for each already known. No firm basis exists for an estimate of the upper bound.

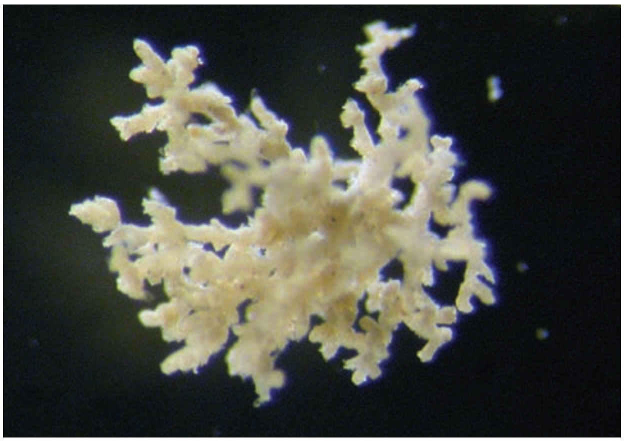
While species are the currency of diversity for animals, plants, and fungi, for most microbes or microorganisms we must speak of kinds or, more technically, phylotypes. Marine microbes include protists, bacteria, and archaea. Like the cells of animals and plants, the cells of protists contain a nucleus, and protists thus belong to the eukaryotes, one of the three basic domains of life. Protists span animal-like protozoa and plant-like algae, and for most protists, we may speak of species. The other two basic domains of life, the bacteria and the archaea, together form the grouping of the prokaryotes. Unlike cells of animals and other eukaryotes, bacterial and archaeal cells do not contain a nucleus.

Microbial cells in the oceans' water column number roughly 100 x 1 billion x 1 billion x 1 billion (10 to the 29th power) and collectively weigh the equivalent of 240 billion African elephants, or 35 elephants of marine microbes per person living on Earth. Although they constitute up to 90 percent of all ocean biomass, most kinds of marine microbes remained hidden until technological marvels, especially fast extraction and sequencing of DNA from large numbers of specimens, revealed their diversity. Even short snippets of DNA can often identify kinds of microbes as well as species of animals and plants. Genetic analysis for identifying plant and animal species is customarily called barcoding because of its analogy to the scannable numbers identifying merchandise in shops. The analogous exercise for microbes is referred to as phylotyping because it relies upon gene sequences that tell about phylogeny or evolutionary relationships to other organisms. From more than 1,200 sites worldwide, Census scientists assembled 18 million DNA sequences of microbial life spanning more than 100 major phyla. Revelations about the microbial world within the single decade of the Census have multiplied estimates of diversity up to 100 times as many microbial genera as previously thought. A single liter of seawater can contain more than 38,000 kinds of bacteria; a gram of sand, between 5,000 and 19,000. Within a particular range of body sizes studied by the Census, 20 million or more types of microbes are likely to exist. Encompassing a wider span of sizes and including parasites and all the microbes that live within marine animals—in the gut of a fish or jelly, for example—up to 1 billion kinds of marine microbes may live in the oceans. Between 100 and 1,000 kinds of microbes may exist for each larger marine species.

The continually rising number of known kinds of life reinforces the conclusion that the Age of Discovery has not ended. Opportunities abound to discover marine species and kinds of marine microbes. We now share some recent discoveries, beginning with a surprise from the Mediterranean, illustrating that the qualities as well as numbers and quantities of biodiversity matter. In the deep Mediterranean, scientists encountered three new species from a little-known group called loriciferans that dwell in seafloor sediment and spend their whole life cycle without oxygen. These loriciferans are the first animals known to thrive without oxygen. They may resemble life forms that thrived during Earth's early history, before oxygen came to abound in the atmosphere and oceans.



13. Anaerobic animals living without oxygen have been imagined by science fiction writers but were not proved to exist on Earth until 2010. In the deep Mediterranean, a Census team found and added three new species to the few known species of the group called loriciferans. Unknown until the 1980s, loriciferans can live their entire lives hidden in sediment on the seafloor without oxygen. The *Nanaloricus cinzia* grows to about 0.3 millimeter long and 0.1 millimeter wide, comparable to the head of a pin. *Image: Roberto Danovaro*



14. The foraminiferan-like protist called Komokiacea were unknown in the deep Southern Ocean. Census explorers uncovered 50 species there, of which 35 were unknown anywhere. The snowflake-like creature in the photograph measures a few millimeters, the size of a flea, and its shell made of sediment grains lends the light beige color. *Image: Andrew J. Gooday*

Like European waters, the Great Barrier Reef and Ningaloo Reef off Australia are much visited. Nevertheless, when Census scientists explored the two locales, they estimated between one-third and one-half of the hundreds of soft corals were new species. Just 22 small heads of dead coral from the Central Pacific contained about 30 percent of the crab diversity of all Europe-

15. This remarkable red worm, between 20 and 30 centimeters long, discovered by scientists investigating the Mid-Atlantic Ridge turns out to belong to a completely new family. In fact, it is not a worm, as they initially thought, but an "enteropneust" that has more in common with vertebrates than with worms. *Image: David Shale*

16. In the inhospitable environment on a vent in the southeast Pacific near Easter Island, Census explorers discovered the yeti crab, *Kiwa hirsuta*. Given a species name for its hirsute appearance, its white, hairy look has prompted the nickname yeti for the abominable snowman, or yeti. The remarkable crab belongs to a new species and new genus and family, too. *Image: Cindy Lee Van Dover*

an seas; nearly half of the species, recognized by DNA barcoding, were found just once and over three-quarters of the species were found in just one location.

To learn what new creatures colonize coral reefs, Census scientists developed Autonomous Reef Monitoring Structures (ARMS). Built of layered plastic, ARMS resemble empty dollhouses and mimic the "nooks and crannies" of a natural reef. When creatures drifted or moved into ARMS on the French Frigate Shoals near Hawaii and scores of other sites, researchers could perform standard surveys contributing to a global picture of reef biodiversity.

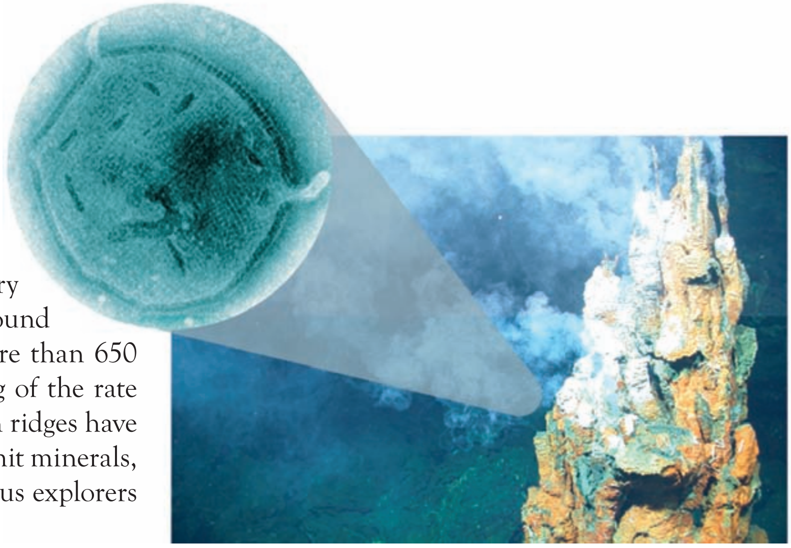
In less familiar waters, unknown species of course also abound. A survey in the Southern Ocean around Antarctica multiplied the number of Antarctic gelatinous zooplankton two to three times. Expense has discouraged sampling, especially in the Southern Ocean below 1,000 meters. During the International Polar Year (2007–2009), however, Census expeditions sampled the abyss, finding more than 700 likely new species among the 1,400 species of invertebrates they sampled. For example, although the protists called Komokiacea were not known to live in the Southern Ocean deep sea, now 50 species are reported, of which 35 were unknown species. Census explorers even found marine life photosynthesizing in the dim light under ice.

In the Ryukyu Trench near Japan, deep-ocean explorers photographed the deepest comb jelly ever recorded. It was attached to the bottom at 6,000 meters below sea level, about two-thirds the height of Mt. Everest (8,848 meters). Even in the well-studied Gulf of Maine, just a few samples in one basin revealed numerous new regional occurrences of species, and expeditions to the less-explored areas such as the slope and seamounts nearest to the Gulf uncovered new species.

One Census investigation lowered rather than raised diversity, in this case, affecting the diversity of fishes. Because an animal may change shape as it passes through stages of life, the young and old may be mistaken as different species. But its genes will not change, and DNA sequences can reveal that the two stages are the same species. Previously, the alien-like Mirapinnidae (tapetails), Megalomycteridae (bignose fishes), and Cetomimidae (whalefishes) constituted three different families in taxonomy based on their appearance and behavior. Census investigations aided by DNA showed, however, that species assigned to those three families were in fact the larvae, males, and females of one single family, the Cetomimidae.

Census investigators, in a sense, compensated for this "loss" of diversity that existed only because of a taxonomic misunderstanding by discovering many new species, one of them a photogenic and authentic new crab in an inhospitable place, an underwater hydrothermal vent. Hydrothermal vents, some called black smokers, occur along ridges where tectonic plates pulling away from each other make new rock. Cold seawater circulates down through cracks between two plates and heats up as it passes through hot rock. The hot solutions carrying minerals and sulfides emanate from the vents and fuel life in extreme conditions and without photosynthesis. On a vent in the southeast Pacific near Easter Island, Chile, Census explorers discovered the yeti crab, *Kiwa hirsuta,* which is not only a hairy new species, but also a new genus and a new family. Other Census scientists have fully cataloged yeti and its known kin among the squat lobsters in oceans worldwide.

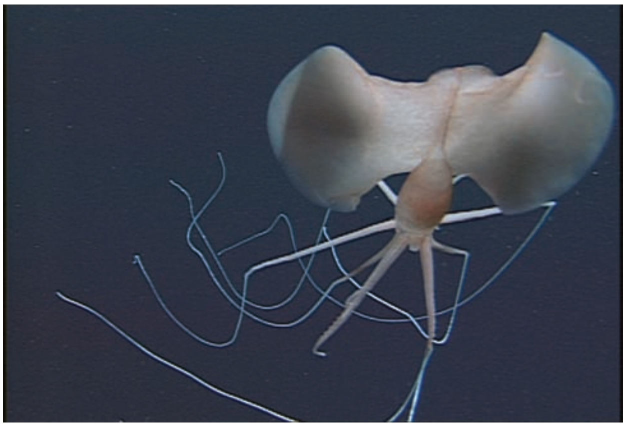
For sports, books of records compile extremes, such as fastest sprint or fastest pitch. The Census established records. The records, beyond attracting the eye, establish the span of marine diversity. Census prospectors of vents located the deepest (5,000 meters), hottest (407°C), northernmost (73° N, Arctic), and southernmost (60° S, Antarctic) "black smoker" hydrothermal vents known so far. Since the discovery of the first one in 1977, scientists have found about 1,000 hot vents and described more than 650 new species from them with no lessening of the rate of discovery. Only 15–20 percent of ocean ridges have been surveyed. Cold vents or seeps also emit minerals, methane, and sulfides, but are cool. Census explorers found 600 new species around seeps.



17. This newly described microbe, a thermoacidophilic archaeon found in a hydrothermal vent deposit from the Eastern Lau Spreading Center in the South Pacific near Fiji, exemplifies the rare biosphere. Wherever Census researchers looked, they found many species in a sample represented by less than one in 10,000 of all individuals, including those that occurred only once. *Microbe image: Anna-Louise Reysenbach and colleagues, 2006. Vent image: Anna-Louise Reysenbach*

Biggest also qualifies as a record and extends diversity. A new giant species of spiny lobster, *Panulirus barbarae,* found off Madagascar weighs 4 kilograms and its main body extends 50 centimeters. Census expeditions found frequent gigantism in Antarctic waters. They collected huge scaly worms, giant crustaceans, sea stars, and sea spiders as big as dinner plates, testifying to longevity in cold conditions where slow growth prevails. Giant *Macroptychaster* sea stars grow up to 60 centimeters across.

Census scientists described large, unusual squids that had recently been discovered around the world in waters deeper than 1,000 meters. Up to 7 meters long, these squids have large fins. Their long, thin arms and tentacles have a strange elbow-like bend near the body. Since their discovery, scientists have found that these squids are adults of the newly described family Magnapinnidae, or bigfin squids.



18. In waters deeper than 1,000 meters, scientists found a group of large, unusual squids up to 7 meters long and waving large, long fins. They constitute a new family Magnapinnidae, aptly called bigfin squids. *Image: © Monterey Bay Aquarium Research Institute*

Just as the too-far or too-deep are rich in new kinds, so too are the too-tiny to see. During an 11-month study in 2007, scientists sequenced the genes of more than 180,000 specimens from the western English Channel alone. The rare was common. One in every 25 readings yielded a new genus of bacteria (7,000 genera in all), quantitatively demonstrating that humans know less about the small than about the large. Many rare species in a sample contradict the generality of a few species predominating. Wherever Census researchers looked, they found many kinds of microbes in a sample represented by less than one in 10,000 of all individuals, including individuals that occur only once. They hypothesized that many kinds, now rare, could become dominant if environmental changes favor them.

Researchers found some marine microbes are everywhere, while others have limited distributions. The rare make up most of the microbial diversity in the oceans. Indeed, rare is common not only for marine microbes but for many taxa and regions.

Rescuing marine life from the category of extinct stands high among the gratifying increases of diversity encountered by Census scientists. They confirmed a contemporary Jurassic "shrimp" thought extinct 50 million years ago in Australian waters. As a record of antiquity, *Neoglyphea neocaledonica,* found on an underwater peak in the Coral Sea, ranks as one of the oldest marine organisms discovered by Census scientists, followed closely by a living fossil found in the Caribbean. *Pholadomya candida* is the only known remaining species of a genus of deep-water clams that flourished worldwide for more than 100 million years from Triassic to Cretaceous times (200 million to 65 million years ago). Thought since the 1800s to be extinct, this living fossil was found at 3 meters depth along Colombia's Caribbean coast. The discovery also confirmed that the clam lives in shallow water, feeds by filtering suspended material rather than by trapping bottom detritus as previously thought, and provides the opportunity for genetic sequencing of an ancient lineage of bivalves to learn its evolution.

Lifespan as well as antiquity distinguish species. In the Northeast Atlantic, Census scientists discovered a new species of oyster, *Neopycnodonte zibrowii,* that forms reefs on deep cliff sides. Radiocarbon dating revealed that individuals reach 100 to 500 years

19. Species thought to be extinct have been rediscovered. For example, Census scientists found a Jurassic shrimp, *Neoglyphea neocaledonica* (left) thought to have become extinct 50 million years ago, and they also encountered a living Caribbean fossil, *Pholadomya candida* (right), the only remaining species of a genus of deep-water clams that flourished worldwide for more than 100 million years and was thought during the 1800s to have vanished long ago. *Shrimp image: Bertrand Richer de Forges and Joelle Lai. Clam image: Juan Manuel Díaz*

20. Sampling near the shore of the Aleutian Islands (Alaska, USA) in 2008 uncovered a new species of large brown seaweed, the Golden V kelp, *Aureophycus aleuticus,* distinct enough to be assigned to a new genus. This kelp with characteristic V-shaped blades, or "leaves," can grow as long as 3 meters. Even the relatively well known nearshore environment still harbors unknown species. *Image: Max K. Hoberg*

of age, placing them among the longest-lived mollusks yet known. For even more astounding longevity, Census takers at cold seeps found straw-like tube worms, *Escarpia laminata,* a meter long at the sunless seafloor with an estimated age of 600 years.

Large and conspicuous species in relatively well known shallow waters still await discovery. Sampling in the Aleutian Islands (Alaska, USA) in 2008 revealed a new species of large brown seaweed, the Golden V kelp, *Aureophycus aleuticus,* distinct enough to be assigned to a new genus.

Beyond colorful examples of diversity found and refound, Census work—especially the decade-long compilation of occurrence records for marine species in OBIS—allows mapping of the levels of biodiversity in different regions of the oceans and for different taxa, and then analysis of which environments favor diversity. Two major patterns emerged from a global study of 13 taxa from zooplankton to mammals: diversity in the open oceans peaked in mid-latitude or in subtropical "strips" in all oceans, while coastal species were most diverse in tropical areas such as Indonesia, southeast Asia, and the Philippines. Sea surface temperature was the only environmental predictor highly related to diversity across all 13 taxa. An unprecedented review of all known marine biodiversity in 25 regions confirmed the coastal pattern.

While the Census firmly established the major patterns, exceptions are the rule. Some locations with temperatures near freezing had higher diversity than some locations with tropical waters. And some taxa do not always follow the general latitudinal trend of highest diversity in tropical regions. Along rocky shores, echinoderms and gastropods display regional hot spots rather than continuous gradients in diversity, while some seaweeds (macroalgae) peak in diversity (and biomass) at higher latitudes. Much deeper, along the continental margin sloping from the shelf to the abyssal plain, the diversity of bottom dwellers peaks at mid-slope between 2,000 and 3,000 meters deep. Here depth matters more than latitude.

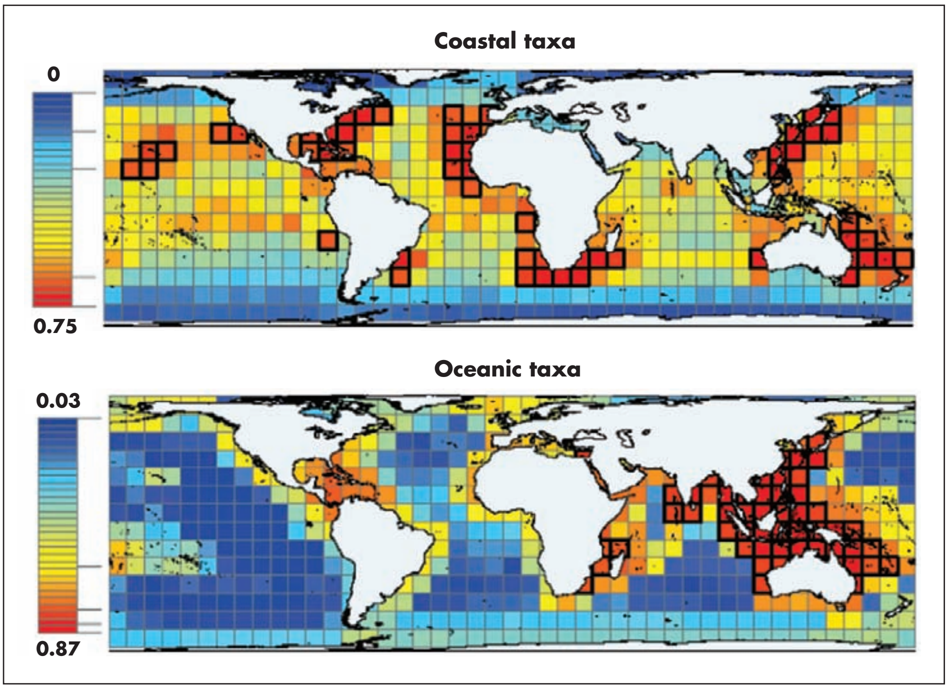
The Census database facilitates creation of comprehensive lists of known species (excluding most microbes) for all regions, whether defined by politics, economics, or geography. The set of studies involving 25 regions extending from Australia, China, and India to the Caribbean, Mediterranean, and Antarctica yielded species lists ranging between about 3,000 in the Canadian Arctic and 4,000 in the Baltic to about 33,000 in species-rich regions such as Australia and Japan. The median region had about 10,000 known species. Crustaceans, mollusks, and fishes are the most numerous in this array and comprise about half of known species diversity.

Census scientists also inventoried astonishing diversity of deep-sea species that have never experienced sunlight. Revealed by deep-towed cameras, autonomous free-swimming robots, and smart nets that open at programmed depths, animals known to thrive in an eternal watery darkness now number 17,650, a diverse collection of species ranging from crabs to shrimp to worms. Most have adapted to diets based on meager droppings from the sunlit layer above, but others live off bacteria that break down oil, sulfur compounds, and methane, the sunken bones of dead whales, and other unlikely foods.

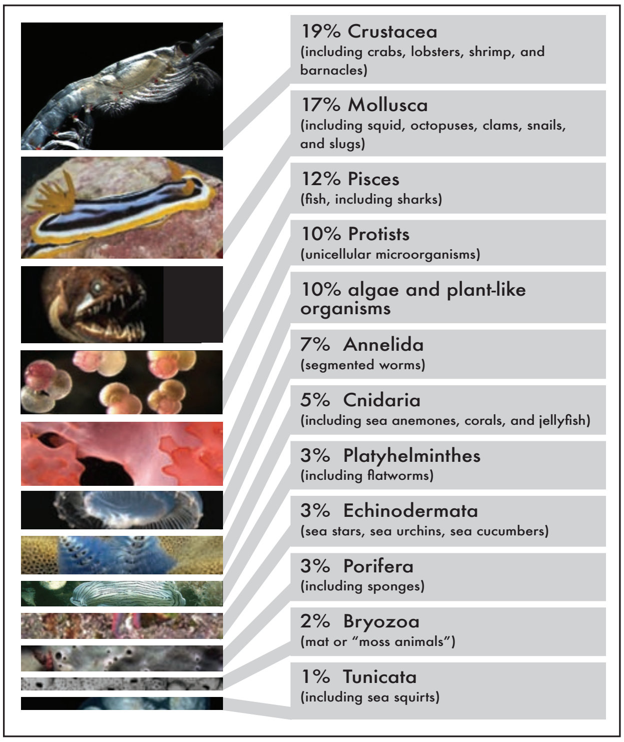
While opening opportunities for discovery, the accumulating mass of data sometimes overwhelms the mind's ability to comprehend. When considering 10,000 species or specimens at one time, DNA again comes in handy. DNA is fundamentally digital. Each nucleotide in a strand of DNA is a thymine, cytosine, adenine, or guanine and can be coded in zeros and ones, or as a colored stripe. A short "barcode" region distinguishes the species to which a specimen, including a fin or tentacle or other fragment of tissue, belongs. This technique was first published in 2003; the fast-growing reference library of marine species with barcodes now tops 35,000 covering more than 20 phyla.

Statistical analysis and graphics help extract meaning and pattern from diversity recorded in large databases. One approach that the Census applied innovatively converts nucleotide sequences of barcode regions into "indicator vectors" and then calculates how closely these vectors resemble each other from the distances among them. Displays of the correlation matrices, dubbed Klee diagrams for their resemblance to the geometric paintings of Paul Klee, graph the separation of species and the intensity of relations among species. A single Klee diagram illuminates the relations and descent of animals of more than 5,000 species in 8 widely separated groups. Colors and distances reveal discontinuities corresponding to species- and higher-level taxonomic divisions. Sponges and bony fishes have the least kinship among eight major phyla, while sea stars (echinoderms) and sharks (elasmobranchs) make surprising neighbors. Klee diagrams also offer colorful "fingerprints" characterizing the diversity of life in different bodies of water. For example, DNA samples from the zooplankton of the Sargasso Sea versus the Celebes Sea make distinct Klee patterns.

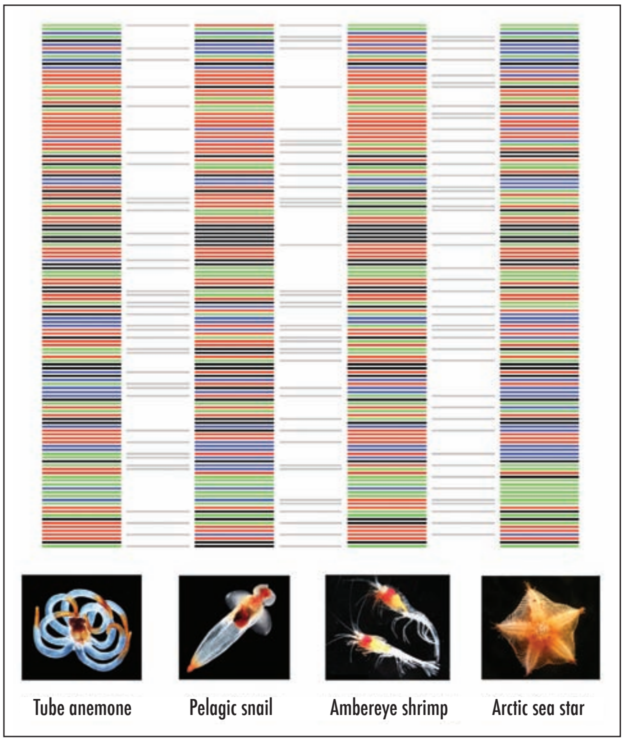
Exploring diversity in all realms of Planet Ocean, Census of Marine Life explorers newly observed millions of specimens. More than 1,200 of the collected specimens are now formally described as new species, while 5,000 more are probably new to science and awaiting description and addition to the marine catalog of diversity. Globally, the collective efforts of all marine biologists drawing on specimens collected over many decades are adding more than 1,600 marine species per year. Partnering with other groups and aggregating information, Census scientists affirmed the probable existence of about 250,000 named, known species and helped to make an authoritative, accessible list of these now approaching 200,000 and to develop Web pages for more than 80,000. They sequenced DNA identifiers for more than 35,000 species that make possible a compact new view of the relatedness of all marine life. Capturing DNA for tens of thousands of kinds of marine microbes, Census researchers estimated that up to a billion exist. While at least a million kinds of life earning the rank of species are estimated to live in the ocean, no firm basis exists for a range or upper limit. Of all the life that survives in the oceans, smaller forms appear to outnumber larger forms by 100 to 1,000 times. The oceans burgeon with discovered and undiscovered diversity.



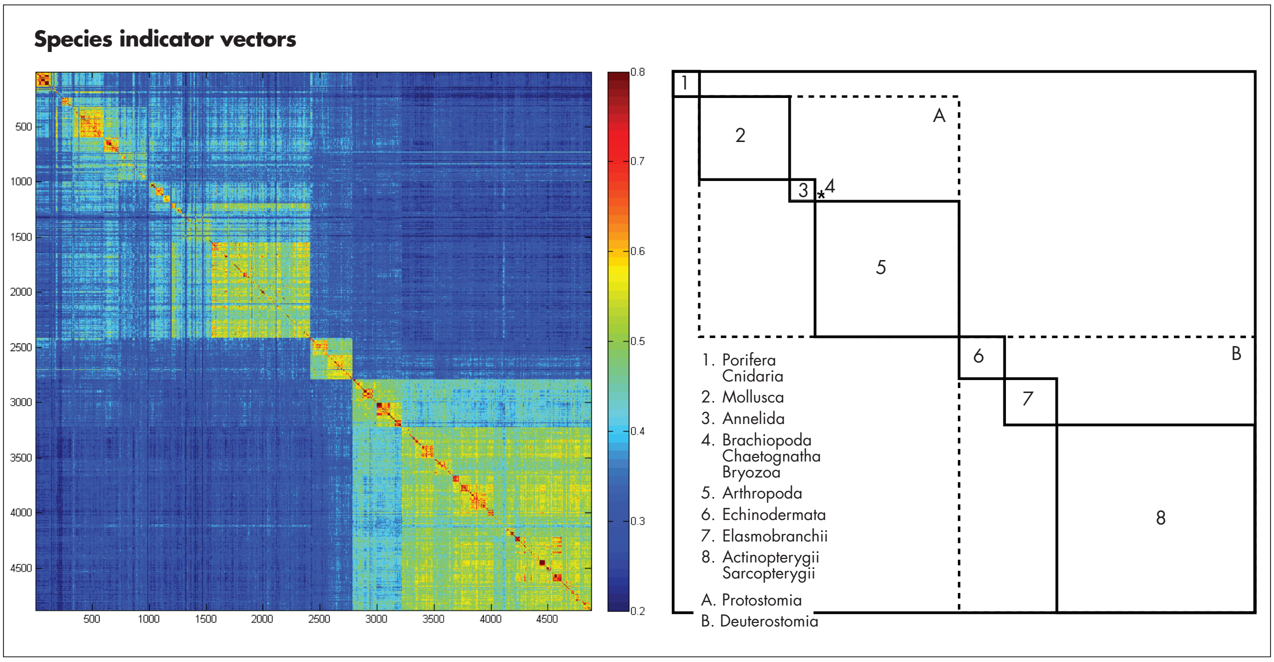
21. Records of 11,000 marine species from tiny zooplankton to sharks and whales assembled in the Ocean Biogeographic Information System of the Census revealed hot spots of species diversity. The diversity of coastal species such as corals and coastal fishes tended to peak around Southeast Asia, whereas the high diversity of open-ocean creatures such as tunas and whales spread more broadly across the mid-latitude oceans. Red indicates areas of high diversity. Horizontal tick marks to the right of the color ramps indicating quartiles of diversity show it takes more diversity in coastal regions to qualify for a high ranking. *Source: Derek P. Tittensor and colleagues, 2010*



22. A census of 25 key oceanic regions rests on information collected during past centuries plus descriptions of thousands of new species during the decade-long Census. Most of the species fall into a dozen groups, including many crustaceans and mollusks, fewer fishes, and only 2 percent other vertebrates. The scarce 2 percent of species that are well-known vertebrates such as whales, seals, and walruses compared with the 98 percent of other creatures in the Census reflects the great diversity of marine life hidden among the other creatures. The regional lists of species set a baseline for measuring changes that humanity and nature will cause. *Images: Russ Hopcroft, Gary Cranitch, Julian Finn, Larry Madin, John Huisman, Katrin Iken, Bernard Picton, and Piotr Kuklinski*



23. Genetic sequences from anemone (*Ceriantharia* sp.), snail (*Clione limacina*), shrimp (*Hymenodora glacialis*), and sea star (*Hymenaster pellucidus*) illustrate the analogy between a sequence of genetic units in the cells of a specimen and the barcodes on items for sale in a supermarket. Each of the four colors represents one of the four nucleotides—cytosine (blue), adenine (green), thymine (red), and guanine (black)—that compose DNA sequences. The gray lines between the colored bars signal genetic differences. The differences among barcodes enable the assignment of a specimen, even a fragment such as a fin or scale, to a species. Specimens of the same species will have identical or almost identical barcodes. *Barcodes: Mark Stoeckle. Images: Cheryl Clarke-Hopcroft, Russ Hopcroft, Bodil Bluhm, and Katrin Iken*



24. Klee diagrams, named for their analogy to the paintings of Paul Klee, display the genetic separation of species and the intensity of relations among species. Blocks of high correlation (red or yellow) on the diagonal reflect affinities within groups of species, corresponding to taxonomic divisions. Each species contributes a line, and a group of closely related species, such as fishes, becomes a group of lines that form a box. Klee diagrams illuminate broad patterns in the genetic structure of biodiversity. The color map depicts correlations for 5,000 marine species from 10 phyla. Elasmobranchii, Actinopterygii, and Sarcopterygii are respectively cartilaginous, ray-finned, and lobe-finned taxa of fishes. The correlations coalesce into a coherent picture of categories of marine life. *Image: Dirk Steinke*

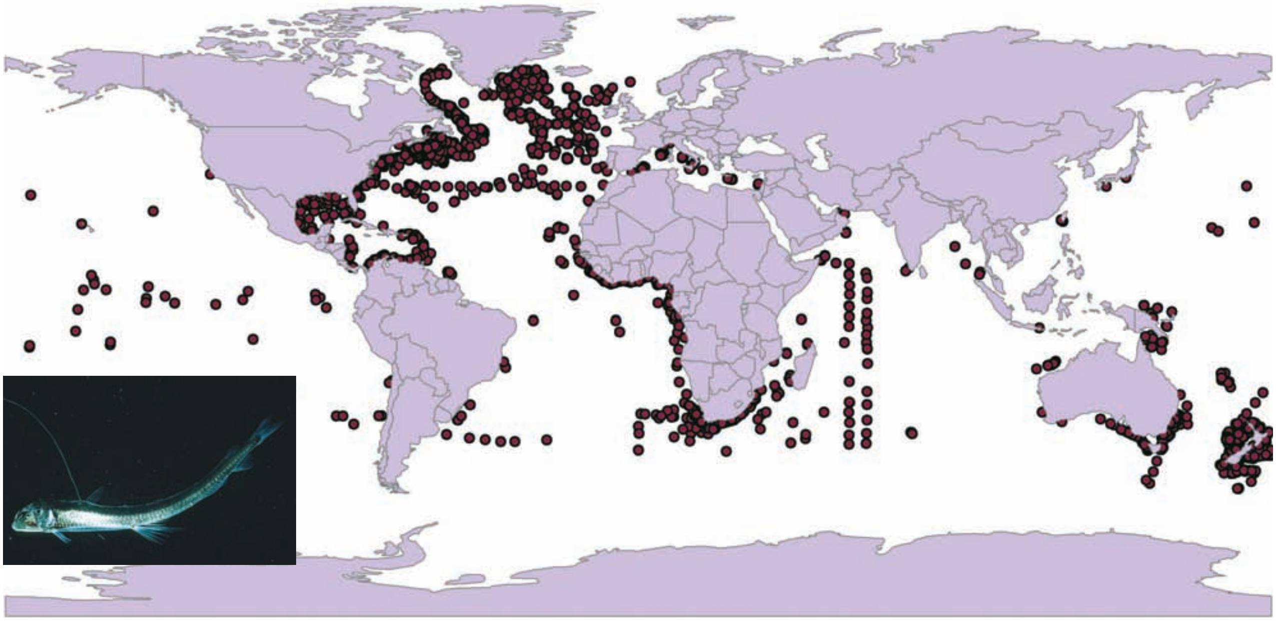
25. Image: Bodil Bluhm

DISTRIBUTION

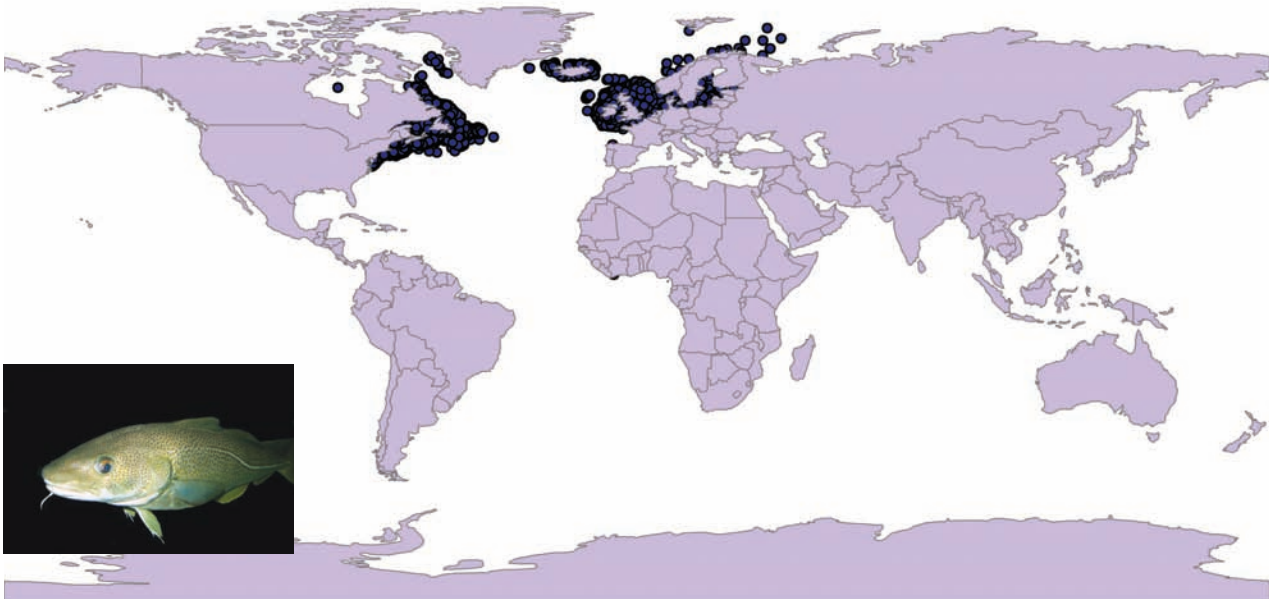
Beyond the kinds or species of life, a census must show the distribution, the addresses and travels, of individuals. Distribution displays where a species is born, eats, and breeds. Congregation shows where it meets its kind and mates. Routes of migration and travel trace the environments where a species prospers, ekes out a living, or merely survives. The distribution maps of a species identify the habitats that will nourish, stress, or starve it.

The millions of OBIS records assembled during the Census decade quickly display where species have been reported. Visiting www.iobis.org and entering the name of a species calls forth a global map of its distribution. Specifying either viperfish or *Chauliodus sloani,* for example, promptly displays its wide range. Entering the Atlantic cod, *Gadus morhua,* maps its narrower range.

Long before a species becomes extinct, circumstances may eliminate it from one of its habitats, an event that its distribution will reveal. Distribution will, of course, reveal elimination or change only if a baseline has been established. For the Gulf of Mexico, 140 taxonomic experts from 80 institutions and 15 countries associated with the Census established the baseline in a book that has been converted into a digital database (www.nbii.gov/portal/server.pt/community/gulf_of_mexico_biodiversity/1950). The data allow anyone to ask how many species of each taxonomic unit live in different sections of the Gulf of Mexico, at what depth, and in what substrate.



26. Entering the URL www.iobis.org accesses the tens of millions of what/where/when records assembled in the global marine life database OBIS. Among fish, the manylight viperfish, *Chauliodus sloani,* whose distribution is shown here in dark red, can be considered the Everyman of the deep ocean. Census data show the fish has been recorded in more than one-quarter of the world's marine waters.
Source: Ocean Biogeographic Information System. Image: Encyclopedia of Life

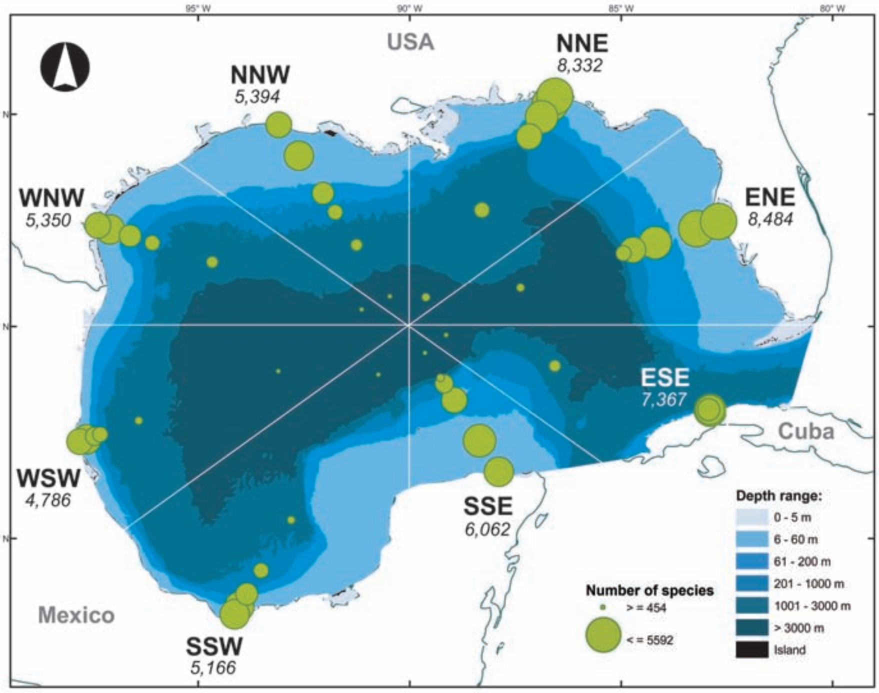


27. Specifying the Atlantic cod, *Gadus morhua,* produces a map of its range, restricted to the North Atlantic and nearby Arctic waters.
Source: Ocean Biogeographic Information System. Image: Encyclopedia of Life

The April 2010 explosion of the Deepwater Horizon rig spilled oil onto the coast, margin, and great depths in the north-northeast octant of the Gulf of Mexico. Decades of survey integrated in the new database set a baseline of 8,332 species in all depths of that octant. Including only major taxonomic units or taxa of animals at all depths in the region of the spill, there are 1,461 mollusks, 604 polychaetes, 1,503 crustaceans, 1,270 fishes, 4 sea turtles, 218 birds, and 29 marine mammal species. Although many species remain to be discovered in the Gulf, the database provides a baseline as of 2009 for assessing the effects of such events as the oil spill and the recovery following its cleanup. The baseline establishes the reference for future measurements.

Where marine animals travel, as well as where they live, affects their success. Their travels set records. Sailfish, *Istiophorus albicans* and *Istiophorus platypterus,* swim fast sprints at 110 kilometers per hour. Atlantic bluefin tuna, *Thunnus thynnus,* migrate east to west and west to east across the North Atlantic about 6,000 kilometers between Europe and North America, and Pacific bluefin tuna, *Thunnus orientalis,* make multiple crossings of the Pacific. Equally impressive as marathon swimmers, humpback whales, *Megaptera novaeangliae,* complete annual north–south migrations of more than 8,000 kilometers. Circumnavigating the entire Pacific, a small seabird, sooty shearwater, *Puffinus griseus,* makes a 64,000-kilometer round trip from New Zealand to Japan to Alaska to Chile and back to the Southern Ocean. This trip, averaging about 40 kilometers per hour, marked the longest-ever electronically recorded migration.

The trials of anadromous fishes as they ascend rivers from the sea for breeding and of their young as they migrate to the sea before returning to their native river exemplify the hazards of travel. Adults going upstream and the young passing down must surmount rapids and fish ladders, and then, escape predators and find food in the ocean. For decades, scientists attached small tags to fish, hoping someone would return them. Some tags were returned, many were lost, and none could tell where a fish had traveled.



28. A map of marine life establishes a baseline for evaluating the outcome of an oil spill in the Gulf of Mexico. One hundred and forty taxonomic experts from 80 institutions and 15 countries associated with the Harte Research Institute, a Census affiliate, established the baseline of known species in the Gulf of Mexico in 2009 and made it available online shortly thereafter. The data answer graphically how many species of each taxonomic group live in different sections of the Gulf of Mexico, at what depth, and on what substrate. The new database sets a baseline of 8,332 species in the north-northeast sector of the Gulf, where the Deepwater Horizon rig tragedy occurred in 2010.
Image: Harte Research Institute

29. The continental-scale acoustic curtains arrayed by the Census tracked migrations of 18 species, including juvenile Chinook salmon, *Oncorhynchus tshawytscha,* thousands of kilometers along the Pacific coast of North America and in rivers, too. The red spots on the map indicate the curtains through which animals swim, signal their passage, and give clues where and how they survive in the oceans. The orange line shows migration of the salmon the size of a banana spanning 2,500 kilometers in three months. The acoustic curtains also revealed an unexpected, long migration of the threatened green sturgeon, *Acipenser medirostris,* along the continental shelf from U.S. to Canadian waters. A surprising group swam north for the winter. *Image: Pacific Ocean Shelf Tracking Project*

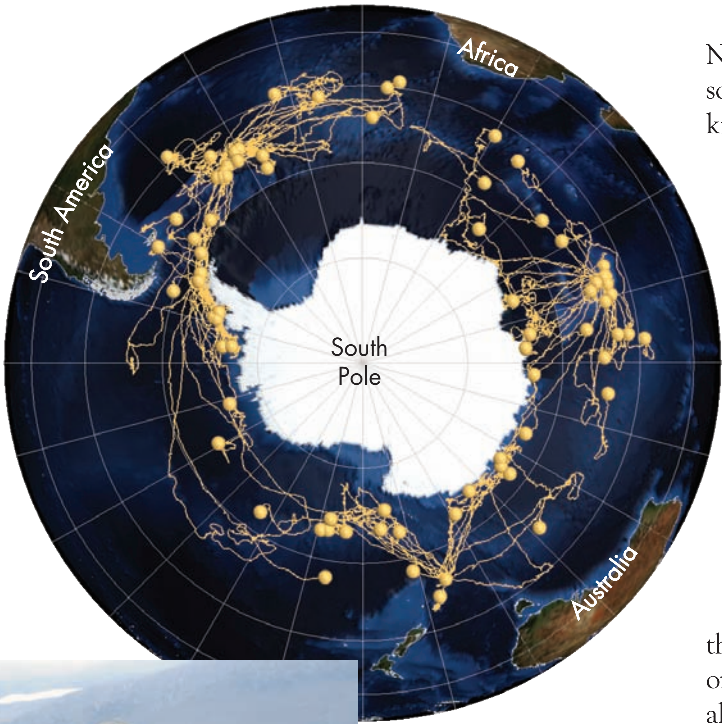
Now acoustics, electronics, and satellites have shifted some of what was unknowable to the provinces of unknown and even known.

The Census arrayed curtains of acoustic receivers on the seabed to track 18 species of acoustically tagged fish more than 3,000 kilometers from California to Alaska, year-round. The searchable public database from the network now contains more than 9 million detections from more than 16,000 tagged animals of all 18 species. The exercise demonstrated that miniature sonic tags and the curtains listening for them could follow the travels of even small animals, such as a salmon the size of a banana, over long distances and through dissimilar waters. Among the many tracked, two juvenile Chinook salmon, *Oncorhynchus tshawytscha,* survived a 2,500-kilometer trip that took more than three months—from the Rocky Mountain headwaters of the Columbia River to the Pacific Ocean and north along the continental shelf of Canada's British Columbia to the coast of Alaska. The research learned about life cycles, movement, and behavior from the point of view of the fish and showed how the mortality of young salmon is apportioned among the habitats they encounter during their early life.

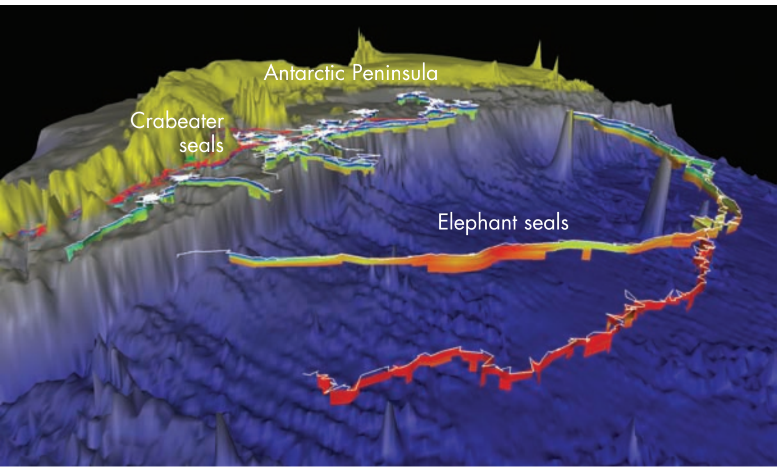
Where and why animals die in the oceans is one of the master questions for a census, and especially challenging for those that migrate long distances. A survey of 3,500 juvenile salmon suggests that only about one of six survives its first month in the ocean, while between 1/25 and 1/100 will survive two years and return to their native river to spawn. Another way to consider the early marine survival of migrating steelhead, *Oncorhynchus mykiss,* and sockeye salmon, *Oncorhynchus nerka,* is to note that survival per week of travel of a group of fish tracked by the Census ranged between about 40 percent and 80 percent.

For species less familiar than Pacific salmon, just knowing where and when they travel expands knowledge. In the case of the threatened green sturgeon, *Acipenser medirostris,* the receiver array revealed annual migration along the continental shelf from U.S. to Canadian waters. A surprising group of sturgeon swam north for the winter. Frequent detection of tagged sturgeon allowed estimating an annual survival of 83 percent.

Tracking marine life in the open ocean requires a different method than tracking them through rivers and along narrow and shallow continental shelves suitable for present curtains of listening devices. Satellites now must communicate with the animal's sensors from afar. The Census researchers devised tags to measure water temperature, light, depth, and salinity around a tagged animal and other tags to sense its pulse and body temperature. Light and pressure sensors on tags estimated chlorophyll, and thus phytoplankton abundance and potential productivity of other life. The light sensors allow calculation



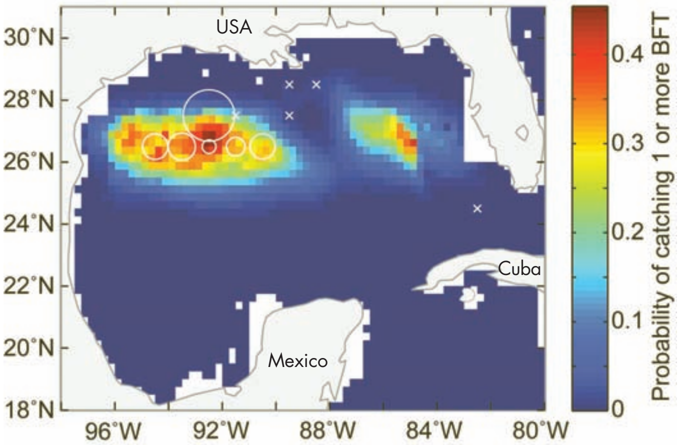
30. Biologging, the use of miniaturized electronic tags to track animals in the wild, revealed unknown behaviors, movements, physiology, and environmental preferences of a variety of ocean animals. Biologging has shown that communities of southern elephant seals, *Mirounga leonina,* from different islands surround the harsh environment of Antarctica, demonstrating the principle that animals inhabit even the farthest reaches of the ocean. *Source: Southern Elephant Seals as Oceanographic Samplers (SEaOS) Image: Daniel Costa*



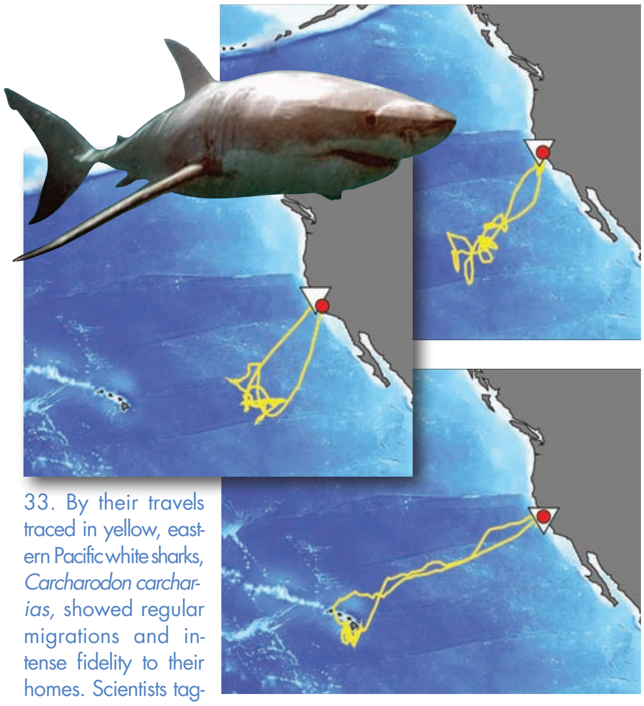
31. Carrying electronic tags that measure location, temperature, depth, and salinity and communicating with satellites as they swam and dove, more than 20 species became auxiliary oceanographers in the Census of Marine Life, reporting the environment that they experienced. The electronic tags on two elephant seals, *Mirounga leonina,* exploring seamounts down to 2,300 meters deep off the Western Antarctic Peninsula reported their paths, and the ribbons of colors on their paths show the temperature and depth measurements that they added to Census data. Seamounts seem to be refueling stations for migratory species. Crabeater seals, *Lobodon carcinophagus,* made tracks closer to shore. *Image: Daniel Costa*

of longitude and latitude from the hour of sunrise and sunset. So-called biologging now brings together behavior, physiology, and oceanography to show how an animal uses its environment. The animals show us their blue highways and why the highways follow the routes they do.

To record a tuna's location, depth, and body temperature as well as the temperature and light in breeding waters in the Gulf of Mexico, Census scientists tagged



32. Conservation requires knowledge of mating areas and nurseries. Spawning Atlantic bluefin tuna (BFT), *Thunnus thynnus,* swim along the slopes in the western and eastern Gulf of Mexico. Red and blue colors on the map indicate high and low probabilities of encountering a bluefin when fishing with longlines in the Gulf of Mexico during 2002 and 2005. A long line caught no tuna at the X's on the map. The narrow band of 24° to 27° Celsius where most tuna swam prompts the speculation that a small change in temperature would change the timing and location of spawning. *Source: Steven L. H. Teo and Barbara A. Block, 2010*



33. By their travels traced in yellow, eastern Pacific white sharks, *Carcharodon carcharias,* showed regular migrations and intense fidelity to their homes. Scientists tagged them in the triangles, and their satellite tags later popped up in the red circles on the central California shelf. One shark swam to Hawaii, two circled in the White Shark Café halfway to Hawaii. Genetic analysis shows that distinct populations persistently return to the same network of coastal places after oceanic migrations.
Source: Salvador Jorgensen and colleagues, 2010

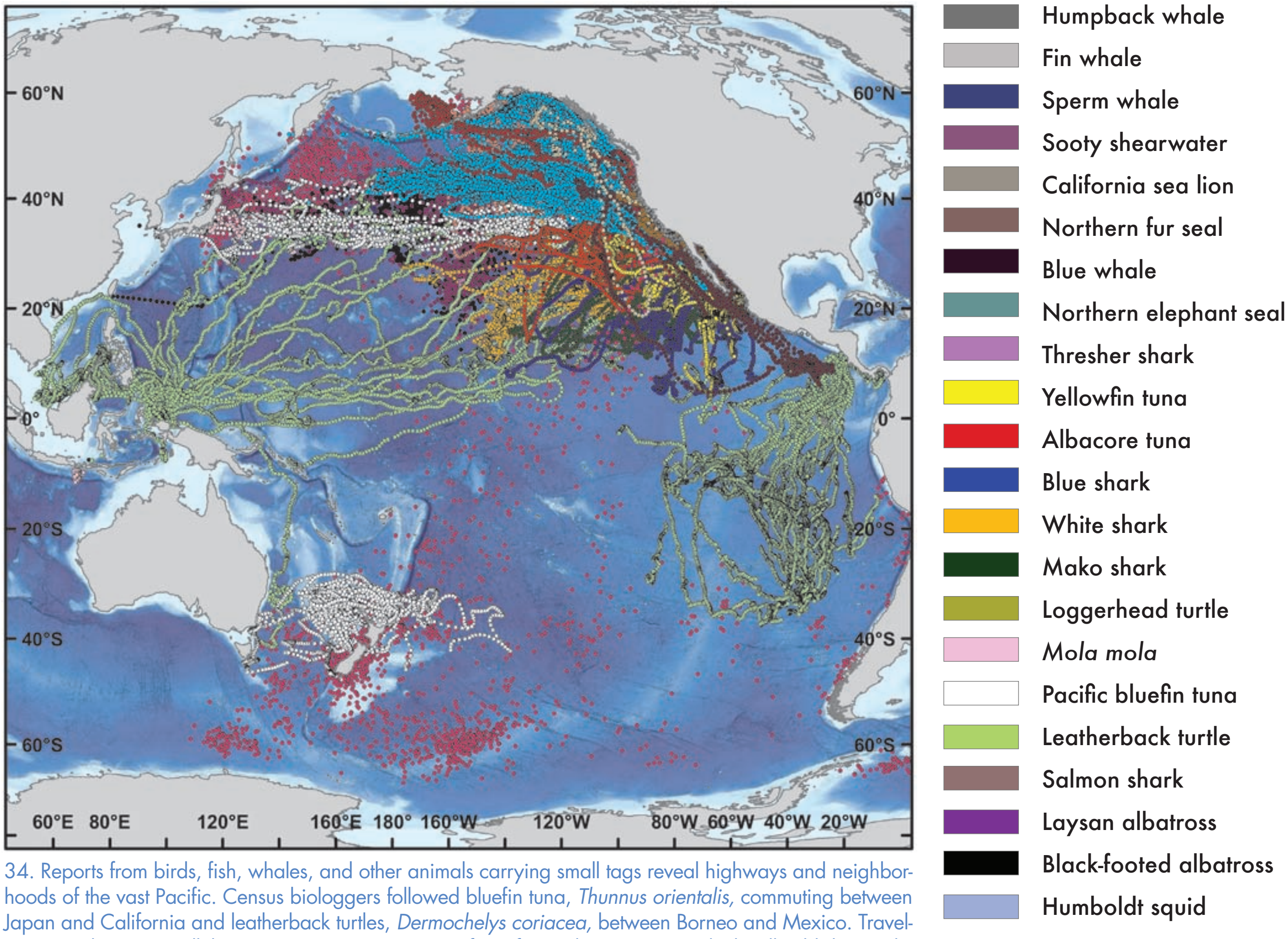
28 Atlantic bluefin tuna, *Thunnus thynnus,* some weighing up to 300 kilograms. The spawning stock for these bluefin has dropped 90 percent in 30 years. Most of the tagged tuna swam near the Florida Straits and in the western Gulf where the continental shelf is steep and surface temperatures are 24 to 27 degrees Celsius.

Combining satellite tagging, passive acoustic monitoring, and genetics, Census trackers found that white sharks, *Carcharodon carcharias,* follow a regular migratory cycle in the eastern Pacific. The sharks migrated from coastal California to a meeting place the Census dubbed the White Shark Café. Visiting the café between Baja California and Hawaii and traveling back, they demonstrated their homing instincts. After journeys of more than 200 days extending to 5,000 kilometers offshore, each shark would return to its precise California address in water about 30 meters deep.

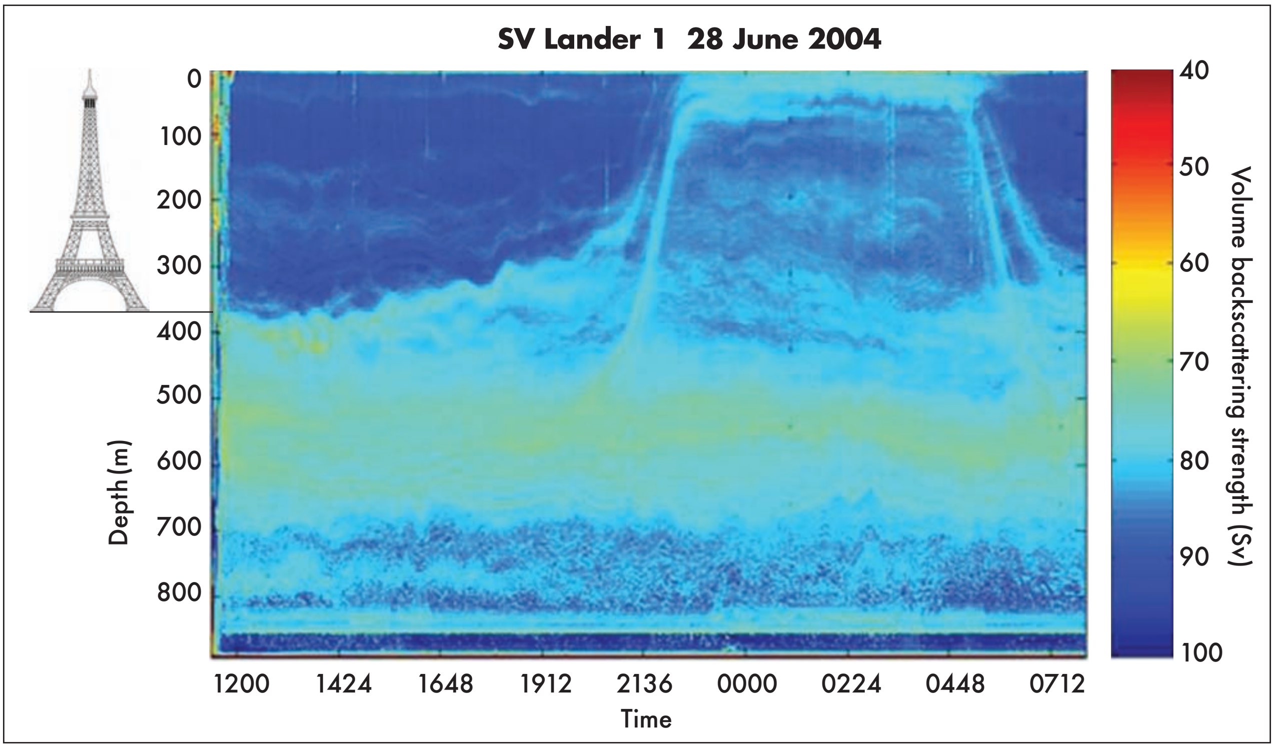
Satellite tracking of leatherback turtles, *Dermochelys coriacea,* in the eastern Pacific during 2004–2007 recorded 12,095 days of travel. During the past two decades, collection of eggs and catching turtles while fishing for other targets has depleted many populations of these turtles by 90 percent. Census tracking located their habitat and migration routes. Combined oceanography and tracking defined the turtles' migration corridor from Costa Rica, across the equator, and into the South Pacific Gyre, a vast region with little food. Consequently, fisheries were closed during the migration, a beginning for conserving the turtles. Further, Census scientists located habitats of female leatherback turtles between nesting periods, when they are endangered by fisheries near the shore and by development on the shoreline. The nearby marine Caletas Wildlife Refuge and improved zoning within the Costa Rican exclusive economic zone are now protecting leatherbacks during this critical phase in their life cycle. The Great Turtle Race Web site created by the Census enabled people to follow the migration of individual turtles and encouraged them to support measures to conserve the animals.

Improved statistical methods pinpointed the locations of tagged animals so closely that other tools could identify behaviors of the animals as they experience their environment. The tools helped show, for example, that male and female grey seals use shelf regions of the northwest Atlantic differently and feed on predictable shallow banks that are restaurants for numerous species.

The sum of tagging and tracking data for a region paints an eye-opening picture of neighborhoods and seaways. While an ocean may look uniform and opaque from an airplane window, underneath the dark blue surface species of tuna and turtles, seals and whales, sharks and squid are each using specific habitats and connecting east and west, north and south, shallow and deep. Evidence from the North Pacific and from the Southern Ocean around Antarctica suggests that every



34. Reports from birds, fish, whales, and other animals carrying small tags reveal highways and neighborhoods of the vast Pacific. Census biologgers followed bluefin tuna, *Thunnus orientalis,* commuting between Japan and California and leatherback turtles, *Dermochelys coriacea,* between Borneo and Mexico. Traveling animals connect all the oceans. *Source: Tagging of Pacific Predators. Image: Blackwell Publishing Ltd.*



35. At dusk in June above the Mid-Atlantic Ridge, scientists encountered a rush hour when animals rise to the surface to feed, as if returning home for supper. Throughout the hours from noon on the left through the night to about 0800 hours on the right, an echo sounder reflected the presence in green of many animals between depths of 400 and 800 meters. During the night from 2100 to 0500 hours, the echoes shown by colors show the upward rush hour, even up to the surface. This daily vertical commute of about 400 meters exceeds the distance from bottom to top of the Eiffel Tower. Spectacular during the summer, the upward commute shrinks during autumn and almost disappears in winter.
Image: Patterns and Processes of the Ecosystems of the Northern Mid-Atlantic project

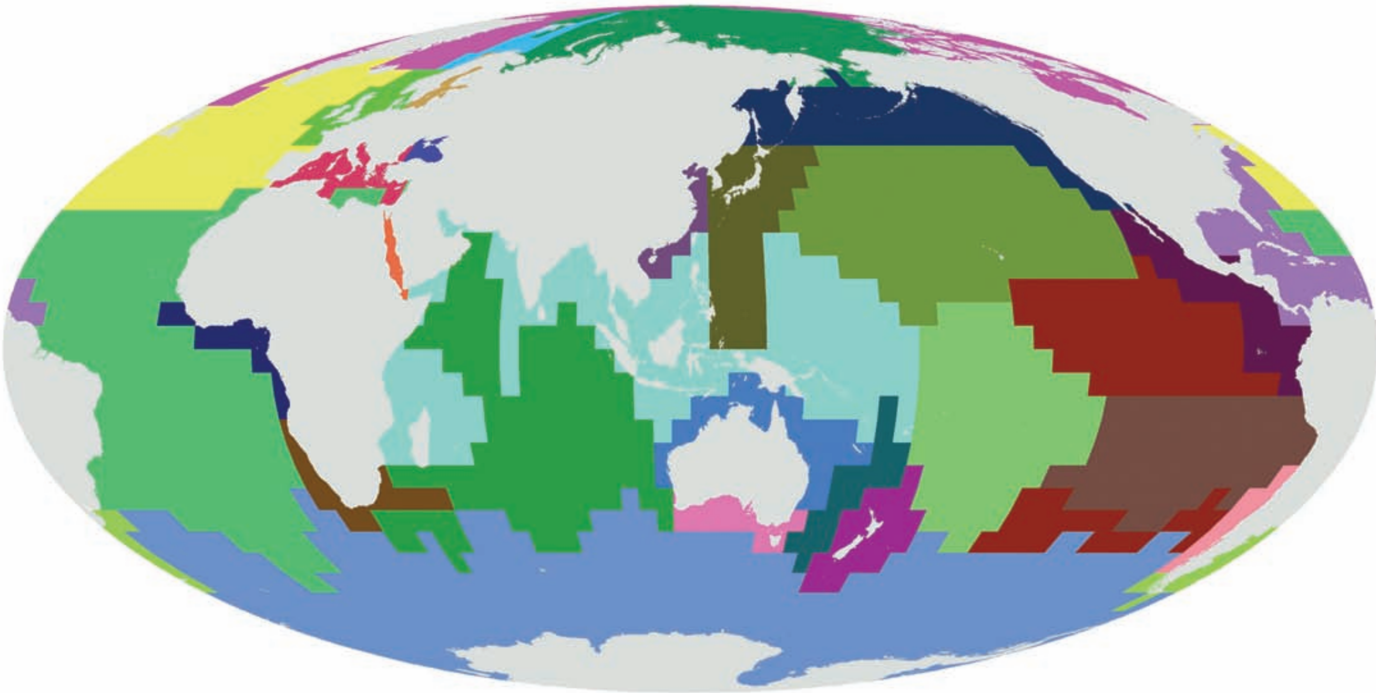
36. Image: Daniel Costa

neighborhood receives visitors from far away. And every species of tagged animal went to unexpected places and did unexpected things, such as white sharks visiting their café or Humboldt squid eating salmon.

In the three-dimensional ocean, living things travel vertically as well as horizontally across maps. Since the 1960s, cameras on animals have logged where they swim or dive. In the Census, tags attached to northern elephant seals, *Mirounga angustirostris,* followed their routine dives down to 600 meters and occasional ones to 1,550 meters. Species that breathe air at the surface often dive to dine. Seals and whales dive from the surface down hundreds or even thousands of meters to find prey with whistling and sonar.

Fishes as well as crustaceans and other invertebrates hide in the dark deep where predators cannot see them, but then surface at night to feed. For fishes and invertebrates, these vertical migrations create a dawn and dusk “rush hour,” where predators and prey commute to and from their preferred deep locations. Some move up from 500- to 1,000-meter daytime depths, rising higher than elevators carry humans in the tallest skyscrapers.

Using new types of echo sounders that could sense events fully to the deep ocean floor as well as sonars that looked upward in deep water, the Census observed a summer rush hour when animals rise to the surface to feed as if returning home to supper. The echo sounder moored 1,000 meters below the water near the Mid-Atlantic Ridge recorded fishes and plankton rising about 400 meters at approximately 2100 hours to the zone where sunlight and photosynthesis had produced food. About 0600 hours, they descended to twilit water below.



37. Spanning microscopic plant-like organisms to whales, the Census produced the first all-taxon maps of global marine species using the distributions of more than 65,000 species from the Ocean Biogeographic Information System. Thirty marine biomes summarize the distributions of many species, each biome representing a region with a distinctive fauna and flora. *Image: Mark J. Costello*

Of course, swirling eddies, large and small, combine horizontal and vertical motion. In the mid-Atlantic, Census researchers found communities with scores of species structured by eddies a thousand meters deep and tens of kilometers in diameter. Large waves traveling deep within the ocean also shape the distribution of life. While a layer rich in life between 300 and 800 meters deep had been known since the 1950s, the Census added evidence of other, deeper layers, 1,500 and 2,300 meters down in the Atlantic.

A different question about distribution that has intrigued biologists for decades is whether some animals thrive in both polar regions. While we know that polar bears inhabit only the Arctic and penguins the Antarctic, biologists have wondered about bipolar mollusks, crustaceans, and fishes. Census researchers identified more than 300 species recorded in both Arctic and Antarctic regions. DNA tests, however, revealed considerable differences, and those showed that few, if any, species truly are bipolar.

Finally, "biogeography" summarizes the distribution of life, marine or terrestrial. Census researchers compared the distributions of 65,000 species of marine animals, plants, and protists to produce the first all-taxa map of global marine species diversity. These analyses distinguished 30 biogeographic regions worldwide.

Such classifications tend to represent the near-surface, which is richer in observations, better than the deep sea. Since the middle of the nineteenth century biologists have discovered 27 habitats from the edge of the continental shelf to the deep trenches, including such recently discovered habitats as whale falls, reefs of cold-water corals, and methane seeps. For most habitats, the global area is unknown or roughly estimated. On the global deep-sea floor, areas that have been carefully sampled are no larger than a few football fields. Nevertheless, with available information about species and the environmental context, researchers have recently offered a new geography for the deep water and deep-sea floor. Divided into four depth ranges, it describes 30 provinces in the water column and 38 for the seafloor, as well as 10 provinces for hydrothermal vents.

More than 100,000 seamounts, undersea mountains that do not rise high enough to be islands, interrupt the deep-sea floor. Because not all seamounts are the same, Census scientists set forth an objective classification. The investigators found previously unexplored seamount habitats, for example, areas dominated by brittlestars, that already bore trawl marks and lost fishing gear upon their first scientific discovery, complicating the attempts to assign seamounts to classes.

Deep or shallow, changes in ocean temperatures, currents, and chemistry would redistribute much marine life. Census researchers predict a decline in diversity in a tropical ocean that becomes warmer, and an increase of diversity at latitudes of about 50 to 70 degrees in both hemispheres.

Up, down, and sideways in the connected water of Planet Ocean, marine life travels in search of food and its own kind, without passports and encountering changing temperature, chemicals, and predators. Some swim, some drift, some stay buried in the mud or attached to a rock. Extreme is normal. No longer opaque, the ocean increasingly reveals its traffic patterns and neighborhoods.

38. *Image: François Sarano*

ABUNDANCE

After naming the kinds of marine life and charting their locations, a census must count or weigh their abundance. Rising abundance indicates a species' health, and declining abundance sends a warning long before the tragedy of its extinction. Counting or weighing the abundance of swimming and drifting life in the three dimensions of the interconnected global ocean confronted the Census with difficulties to overcome. Nevertheless with historical archives, calculation of primary production of food, and new technology to scan vast schools of fish, the Census did penetrate the boundary between unknown and known and occasionally jumped into the province of the formerly unknowable.

For a head start to detection of future trends, Census historians reached backward from the present with unearthed records of fossils, fish tales, and taxes on products made from sea life. In some regions, such as the Mediterranean, humans already removed consequential amounts of sea life 2,000 years ago. History shows people began catching marine life long ago, and their extractions were more widespread and affected a broader range of species than once thought.

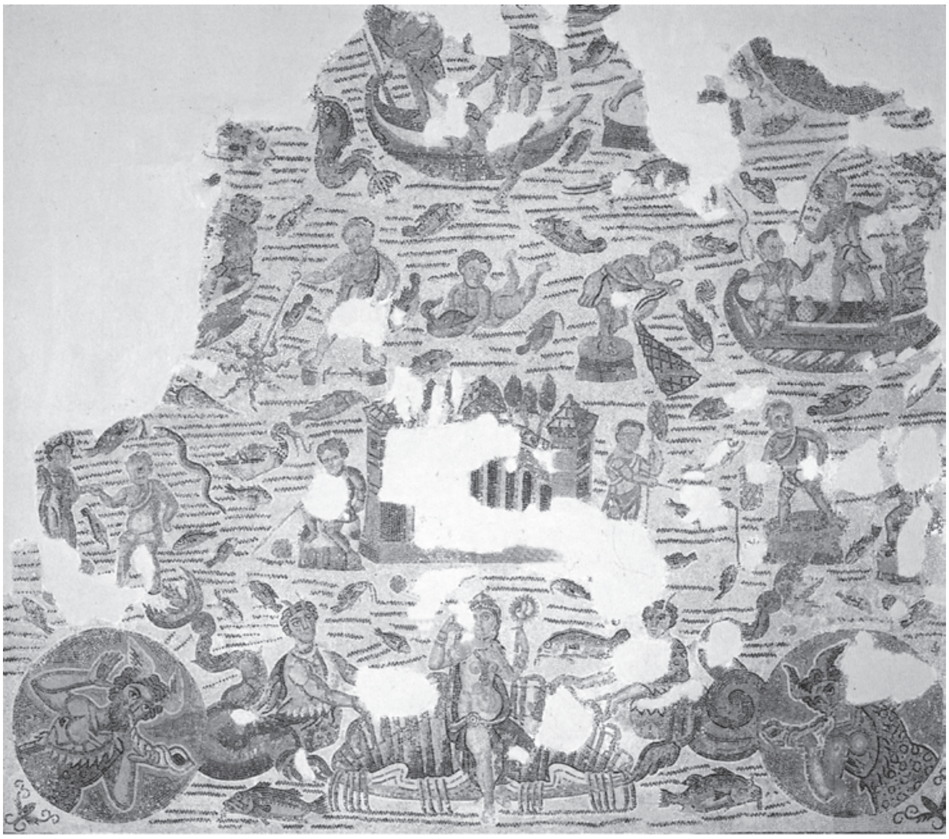
Indeed, since prehistory, our ancestors collected mollusks for their meat and shells. The Census documented shell deposits, or middens, in the Americas, Africa, Europe, Japan, and Papua New Guinea. Studies of the queen conch, *Strombus gigas,* now a threatened species in the Caribbean, suggest depletion by intense Amerindian exploitation before 1492. From the sixteenth to the nineteenth centuries, the conch populations recovered to face a second depletion in the early 1980s.

Since written records began accumulating in archives and libraries five to six centuries ago, fish stories have been saved. John Cabot (1450–1498) provided an example when he wrote that fish along the Canadian coast were "so numerous you could walk across the bay on their backs." Others wrote of native Americans spearing salmon migrating upriver from coastal waters. Even though removals were substantial, some large animals remained.

Even where removals were not yet great, abundance fluctuated. The herring caught in Denmark between 1600 and 1800 provide a quantitative clue to changing abundance, fluctuating by a factor of five, probably owing mostly to variations in weather and climate. Variable climate also appears to have changed salmon populations in the Russian High North long ago.

In a later era, the fluctuating Baltic catch of cod, herring, and sprat during the twentieth century provides data to dissect for causes of change. With accompanying observations of climate, nutrients in the water, and predatory marine mammals, scientists can analyze historical records for the causes of the changing populations. Without some understanding of the causes of these former fluctuations, forecasting changes following natural and human perturbations will be difficult and uncertain.

Recreational fishing also provides valuable observations. Recreational fishers often seek large "trophy" fish and take photographs when they catch them. While fishermen are famously nostalgic for times of greater abundance, their nostalgia appears true.



39. In villages along the Italian coast, lobstering was still an integral part of life in the nineteenth century. *Image: Ente Nazionale Italiano per il Turismo*

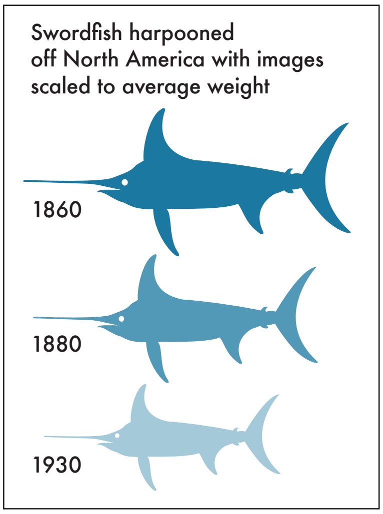
40. A Carthaginian mosaic from the end of the fourth century displays the range of nets, rods, spears, and tridents for catching fish during the Roman era. Thousands of years ago, people caught sea life near the shore and near the surface across wide regions such as the Mediterranean. *Image: "Il mare Com'era"*

41 and 42. While recreational fishing removes much less sea life than commercial fishing, recreational fishers do sample marine life, especially large animals. In 1958, after an excursion on a Key West, Florida (USA) charter boat, a family of recreational fishers displayed their trophies, especially large groupers, subfamily Epinephelinae. In 2007, the size of the fish displayed by the same charter enterprise had plummeted, and the mix of species had changed. *Images: Monroe County Library (left) and Loren McClenachan and colleagues, 2009*

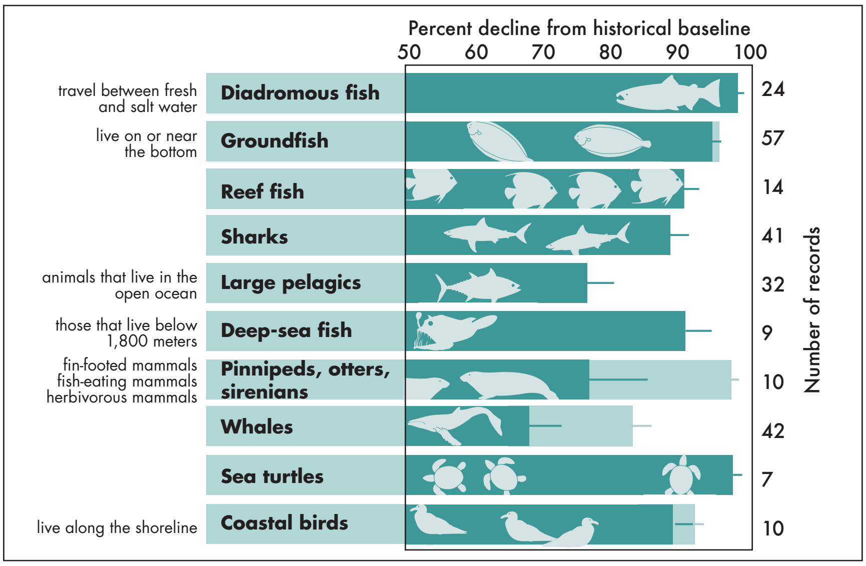
Off the North American coast after the mid-1800s, commercial fishers caught swordfish, *Xiphias gladius,* in numbers varying by a factor of ten. The fish population and the effort expended in fishing raised or lowered the numbers. On the other hand, the average weight of the fish, caught by either harpoons or lines, declined from as much as 270 kilograms in 1860 to near or less than 100 kilograms during the decade of the Census.

To alleviate the historical amnesia of focusing only on trends in the recent 20 to 50 years, Census scientists mined data sources from palaeontological and archaeological evidence to molecular markers, historical records, and fisheries statistics. They established historical baselines for 10 groups of large marine animals to compare with recent abundance. At their low point, the 10 groups had declined by nearly 90 percent on average. Historically, overfishing and habitat destruction lead the ranking of threats to marine life caused by human activities. Since reaching their low point, four groups of species have recovered somewhat. Whales and seals recovered about a fifth. Because the available data are mostly about highly valued, commercially important species, these estimates represent large, exploited species in particular rather than all marine animals. For these valuable animals, the data confirm the feared declines but also offer a few instances of hopeful recovery.

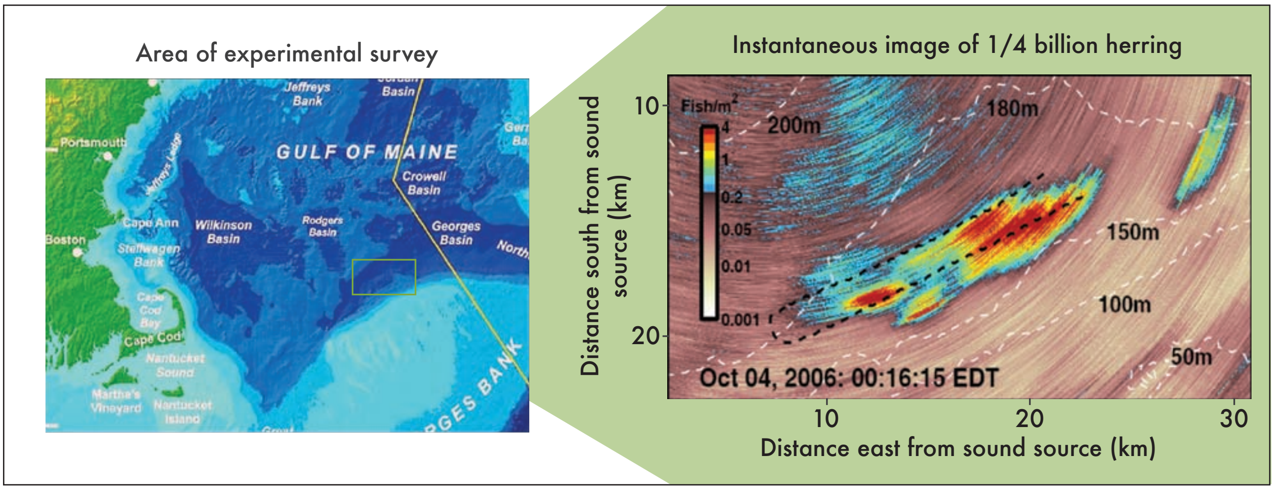
Extractions of target species sometimes cause fast changes, as the trawl fishery off Southeast Australia between 1914 and 1950 demonstrated. First tiger flathead *(Neoplatycephalus richardsoni)* plummeted from early, high catch-rates, and then Ocean leatherjacket *(Nelusetta ayraudi)* and latchet *(Pterygotrigla polyommata),* species



43. From 1860 to the present, the average weight of swordfish, *Xiphias gladius,* caught off the North American coast by either harpoons or lines declined from as much as 270 to near or less than 100 kilograms. A big drop occurred from 1860 to 1930. *Source: Karen Alexander, Brian R. MacKenzie, and William Leavensworth*



44. Dark-shaded bars indicate that the estimated declines in populations of large marine animals from their historical levels average about 90 percent. Nevertheless, some recovery (shown by light-shaded bars) has been achieved by four groups, including seals, whales, birds, and such bottom-dwelling fish species as flounder and sole. These estimates for exploited species in particular, rather than all marine animals, confirm the feared declines and offer a few hopeful instances of recovery. *Source: Heike K. Lotze and Boris Worm, 2009*



45. Census scientists deployed a new acoustic system to track vast fish populations over tens of thousands of square kilometers of sea along the continental shelf. In a snapshot from continuous monitoring along Georges Bank where the Gulf of Maine begins, the new sonar maps tens of millions of Atlantic herring, *Clupea harengus,* maintaining a school formation as large as Manhattan island, sometimes as densely as eight fish per square meter. *Image: Nicholas Makris and Purnima Ratilal*

abundant in the initial years of the fishery, virtually disappeared from catches in later years. In contrast, recoveries tend to be slow. Increases are most marked for species whose exploitation ended at least 100 years ago and species that became protected in the early to mid-twentieth century.

For the valuable and long-lived tuna, historians of the Census examined the boom of catches from 1900 to 1950 that preceded the collapse of once-abundant populations of Atlantic bluefin tuna, *Thunnus thynnus,* off the coast of northern Europe. Dusting off sales records, fishery yearbooks, and other sources, the researchers found majestic bluefins teemed in northern European waters for a few months each summer until an industrialized fishery geared up in the 1920s and literally filled the floors of European market halls with them. Generations ago Atlantic bluefins arrived in the northern waters by the thousands in late June. During the mid-1800s, fishermen welcomed these tuna as partners who pursued garfish into nets set close to shore. Before World War I, the bluefins were rarely captured, and even coastal sightings were exciting events. One 2.7-meter tuna washed up on a German shore in 1903.

After World War I, more boats, know-how, and equipment such as harpoon rifles and hydraulic net lifts helped fishermen increase annual catches from virtually nothing in 1910 to almost 5,500 tons of tuna by 1949. In 1929, Denmark built a tuna cannery. In 1949, Norway had 43 boats pursuing tuna and soon 200 boats. The booming catches helped strip the Atlantic bluefin population in a blink of time—1910 to 1950. The species virtually disappeared from the region in the early 1960s and is still rare today.

Farther up the chain from sea to restaurants, Census scientists found another index of marine abundance. Over 150 years of inflation-adjusted prices from menus, most from American cities such as New York, Boston, and San Francisco, revealed shifting tastes and supplies of lobster, swordfish, abalone, oysters, halibut, haddock, and sole. For example, on San Francisco menus, which started to feature the slow-growing abalone in the 1920s, prices spiked when stocks along the California coast declined in the 1930s and again in the 1950s. Finding 10,000 archived menus that showed date and city expanded the province of the known.

If a form of sea life disappears from a menu, has it disappeared from the oceans? Census researchers struggled with the question of regional or global extinction. A basic statistical problem is to evaluate the role of "false absences," that is, where a species was present in the local community, but not found in recent surveys from that community. The vastness of the oceans makes certainty about extinction hard except for large animals that spend lots of time at or near the surface. The Census developed new methods to adjust for false absences and to compare historical lists of marine species prepared in a largely qualitative way with data from modern quantitative surveys. Application of these methods during the next decade should provide more accurate assessment of marine extinctions. Now, existing information shows many species becoming rare but proves few extinctions.

Beyond inferences from catches, sightings, and calculation, Census scientists observed the abundance of marine life directly. They deployed a new sensor system to track vast fish populations, or shoals, as well as small schools, over tens of thousands of square kilometers of sea along the continental shelf. The shoals are sensed by sonar, which locates objects by bouncing harmless sound waves off them. The low-frequency sonar waves travel farther and return observations with informative signals far less intense than earlier sonar. The new sonar ranges over an expanse of ocean a million times wider than could previously be studied.

The new technology works best along the continental shelf, so the researchers focused on the shelf waters south of Long Island, New York, and over Georges Bank in the Gulf of Maine. When they first started, they were not looking for fish at all—they wanted to see if their device could locate ancient riverbeds under the ocean floor. But when their reconnaissance images did not match the riverbeds, the researchers went back, and determined that they were seeing fish—tens of millions of them. The new sonar images, updated every minute, continuously monitor the size and density of the millions in the shoals and also the shape of the shoals as they change from hour to hour.

With sonar, the Census scientists saw an abrupt daily queuing of tens of millions of Atlantic herring rising from the seafloor. Beginning from small clusters, tens of millions of fish queued across tens of kilometers along the northern flank of Georges Bank in tens of minutes. The rapidity, synchronicity, and regularity with which these long queues of spawning fish assembled showed the pressure on individuals, first to join, and then to conform with large groups. Beginning with a density of less than one fish per square meter, they became as crowded as eight per square meter.

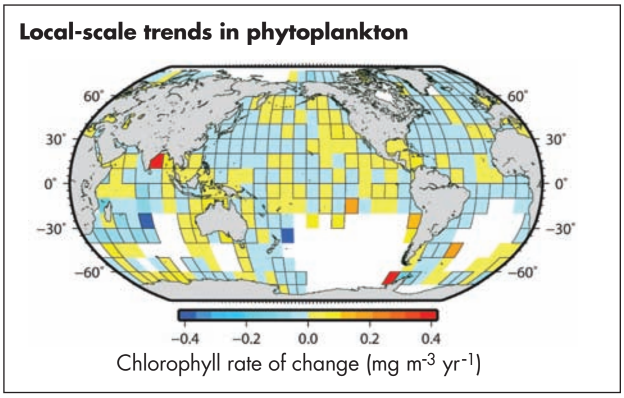
Also exemplifying high abundance, microbial filaments form mats covering an underwater territory of nearly 130,000 square kilometers, about the size of Greece, on an oxygen-starved seafloor off the central and northern coasts of both Chile and Peru. They are among Earth's largest living structures. The massive, diverse microbial community thriving mostly on methane-associated hydrogen sulfide probably represents a living fossil ecosystem of the Proterozoic era 2.5 billion to 650 million years ago, before and during the transition to an oxygenated atmosphere. At mid-depths of the ocean where the mats spread, little oxygen mixes down from the surface or up from the cold, oxygenated water that sinks at the poles and oozes like poured cream along the seafloor to other regions. With so little oxygen, most multicelled life cannot survive. But microbes, such as the large multicellular filamentous ones making up the gigantic mats, can successfully thrive. The largest filaments are about half the width of a human hair and, unlike most bacteria, are visible to the naked eye.

Census explorers found the long bacteria in sulfide seeps at the Galapagos Archipelago, Ecuador, and off the Pacific coasts of Panama and Costa Rica, and speculate that these microbial mats in oxygen-poor layers in the ocean may run from southern Chile to Colombia. Some things are unknown or unknowable because they are too small to see, others because they are too big to see.

Globally, on the deep-sea floor, the Census showed the ubiquitous high abundance of small sea creatures resembling worms (polychaetes, nematodes) and bugs (copepods) as well as localities with high biomass along margins and ridges where methane and sulfur-charged geothermal fluids stream from the seafloor.

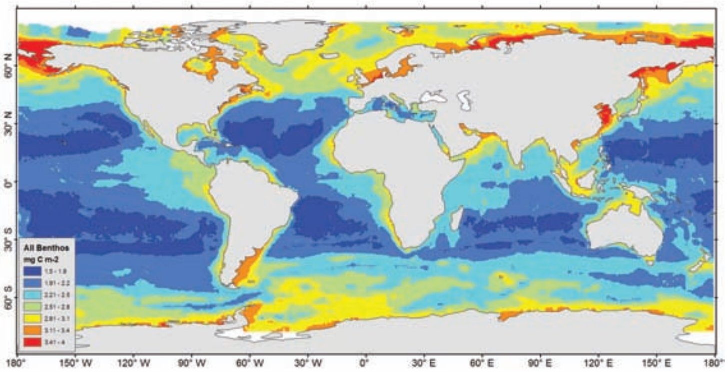
While changes in abundance of particular taxa have been obvious since humans first collected shells along the shore, the question of whether global changes are occurring in all the life that constitutes a trophic level has remained controversial. Most attention has gone to

46. Small life can form large structures. Off Chile, filamentous bacteria of the genus *Thioploca* wove mats covering an area the size of the nation of Greece. Census scientists estimated the mats to weigh about 14 million tons, about one-seventh of the weight of the annual world harvest of commercial fisheries. *Image: Victor A. Gallardo and Carola Espinoza*

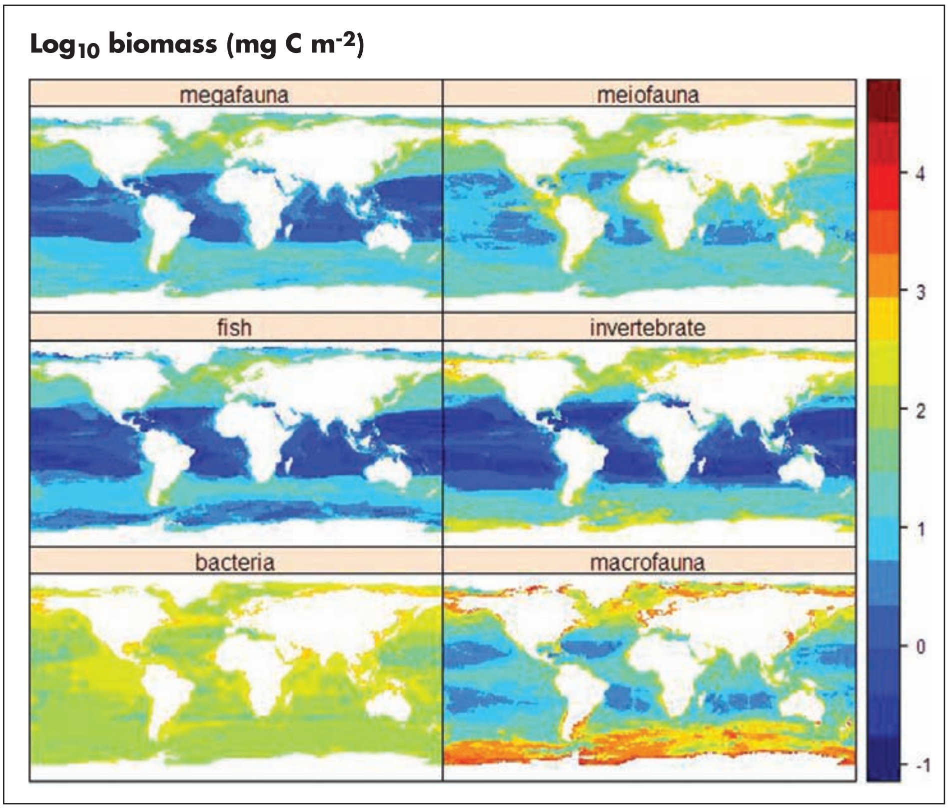


47. Since 1899, phytoplankton chlorophyll measured first by ships and recently by satellites, too, declined in 59 percent of the 364 map cells with sufficient observations for a determination. It increased in the yellow and red cells and declined in the blue. The cells bordered in black experienced statistically significant changes, while white cells had insufficient data. *Source: Daniel G. Boyce and colleagues, 2010*

Estimated seafloor biomass



48. Census scientists used nearly 200 studies to estimate the biomass on the seafloor globally from bacteria through fish and other large animals. The yellow-to-red zones in the map show seafloor biomass reaching 3 to 10 grams of carbon per square meter, or 30 to 100 kilograms per hectare, along several temperate and frigid shores. Carbon typically makes about half of living biomass. This level of carbon accumulation is small compared with the tons accumulated per hectare of land in a forest or even a crop of maize, but still considerable when added over the vast oceans. In general, the tropical seafloor is poor in biomass while the temperate and polar seafloors are rich. *Source: Chih-Lin Wei and Gilbert T. Rowe*



49. A map of the estimated seafloor biomass of bacteria and other kinds of life grouped by size (the small meiofauna that pass through a 0.3-millimeter sieve, the intermediate macrofauna up to 3 centimeters, and the larger megafauna encompassing both invertebrates and fishes) shows that despite the microscopic size of bacteria, their numbers make their mass far greater than the mass of larger and hence clearly visible animals such as fish. Bacteria reach densities of 100 to 1,000 milligrams of carbon per square meter ($\log_{10}$ equal 2 or 3) in the tropics and near continents, whereas fish only reach densities of 1 in the tropics and 10 ($\log_{10}$ equal 0 or 1) elsewhere. *Source: Chih-Lin Wei and Gilbert T. Rowe*

changes in top predators, such as whale and seal populations, which shrank and now are rebounding. Census researchers examined the other end of the food chain. Is the productivity or biomass of the meadows of the oceans, the phytoplankton that feed upper trophic levels, changing? An initial global study involving Census researchers who used indirect observations from ocean-going vessels since 1899 suggests a patchy but significant global phytoplankton decline.

As noted earlier, up to 90 percent of all the weight of life in the oceans and seafloor mud is microbial. “Pyrotag sequencing,” the DNA technique pioneered by Census researchers to ascertain the diversity of bacteria, archaea, and protists, also captures information about relative abundance. Census microbiologists drew diagrams resembling city skylines to show the relative abundance of different kinds of microbes for hundreds of locations. The skylines show a few tall buildings, some of intermediate height, and many low structures that form the “long tail” of the distribution that constitutes the rare biosphere.

Calculation and measurement as well as the history of marine life sighted and caught can be used to estimate abundance as well as extinction and the recovery of some depleted species after intervention. With the exception of such living things as the bacteria in the giant mats off Chile that have an alternative means of synthesizing food, the abundance of life at the bottom of the ocean, the biomass on the seafloor, usually depends on primary food production by photosynthesis in the sunlit water above and its settling to the floor as marine snow. The fall of organic particles largely determines how many thousands of organisms live on a square meter of seafloor and the weight of their biomass.

Census scientists estimated seafloor biomass from primary production, the fall of organic particles, and topography of the seafloor. Primary production concentrates around land where plant nutrients reach the sea. The map of total seafloor biomass which consists about half of carbon, shows its biomass reaching 3 to 10 grams of carbon per square meter or 30 to 100 kilograms per hectare, along several temperate and frigid shores. In turn, calculations can translate the seafloor biomass into estimates of populations of individuals in groups of animals such as fishes and invertebrates and in bacteria. By weight, the populous seafloor bacteria equal about ten times the sum of larger seafloor marine life.

With about a quarter of a million known species and life distributed everywhere in the vast oceans, measuring abundance is finally more difficult than measuring diversity or distribution. In contrast to diversity, which tends to peak in temperate and warmer waters, abundance appears to peak in temperate and cooler waters. Much life, such as the microbial mats, continues to be discovered. Evidence shows that most species entering human commerce decline, often sharply. It remains unknown whether the declines in the few thousand commercially important species have changed the global total biomass of all marine life, but an initial global study suggests a patchy twentieth century decline in the grass of the oceans, the phytoplankton. Overall, we seem to see declining abundance at the top and near the bottom of the food chain, with fishing practices, habitat destruction, and ocean temperatures the most powerful causes. Systematically measuring the abundance of the approximately 250,000 known species and the kinds of microbes as well remains as a task for the next decade. Estimating the abundance of undiscovered species adds mystery and glory to the task.

LEGACIES

The Census imparted urgency to its explorations by setting for itself a life of 10 years, enough time to organize and build to a crescendo in 2010. Much of the worth of such a brief life lies beyond its decade in legacies that go on.

Broadly, three sorts of legacies can already be discerned. Knowledge resting on sound research and recorded with moderation and caution by Census scientists will inform the future. The technology that they invented, improved, and spread will power future discovery. And to the extent that they succeed, they demonstrated work habits—organization and working together—that can make research in future decades more efficient and effective.

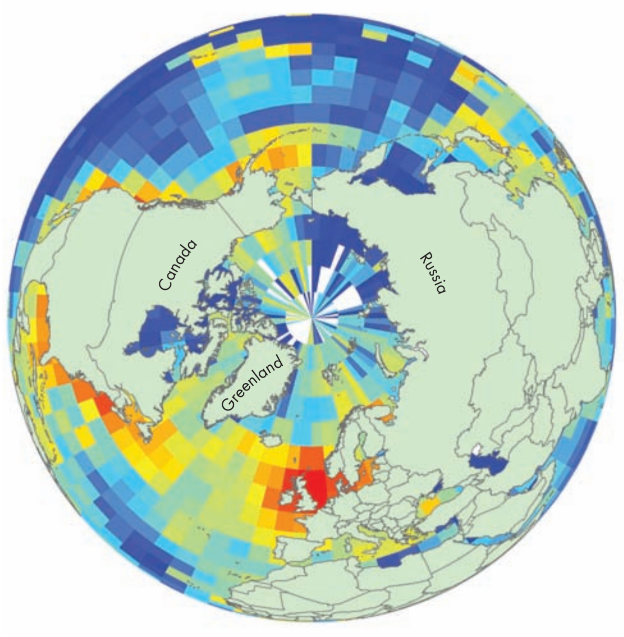
Regarding knowledge, the Census published its results in more than 2,600 scientific papers. Some, the compilation and organization of the known, reveal regional and even global patterns, past and present, and show how marine life fares in different environments and eras. Other papers record new species and many species in new places. They record the travels of marine life and its abundance.

Publicly reported in scientific papers, Census research informs and propels new discovery. Publication of its series of reports in the Public Library of Science and other open-access sites will prove a special legacy because anyone with a computer can read them on the Internet, for free, now and in the future.

With existing data plus its own, the Census built OBIS, the largest archive of data about marine species. In a crescendo of results at the end of the decade, Census scientists proved the power of the globe-encompassing archive to reveal patterns of diversity, distribution, and abundance. Governments have committed to sustain OBIS. By opening OBIS to the public and arranging its continuity and integration with the Encyclopedia of Life and other elements of the "e-Biosphere," the Census created a legacy of infrastructure for future research.

Without reference baselines for today's state of marine life, claims of change due to warmer water and damages from fishing and oil spills can only fuel contention. Similarly, claims of benefits from protection of areas and from regulation of drilling and fishing require proof that the baseline of the present state provides. Selections of marine protected areas by nations and the international Convention on Biological Diversity need baselines. To all these interests, the Census wills a legacy of baselines of marine diversity, distribution, and abundance at the beginning of the twenty-first century.

Technology of an earlier Age of Discovery, such as ships that could span oceans to another hemisphere, continued as legacies to later centuries. Similarly, the Census grants a legacy of barcoding and similar genetic methods for distinguishing species by their DNA sequences, some species too small to see with the naked eye and some cloaked in similar shapes or confused by changing shapes. Going beyond seeing that specimens are different, the Census adds the legacy



50. The global marine life database built by the Census exposes gaps in our knowledge of the known and unknown. The color spectrum from red to blue ranges from many to few records. Blank areas have no records of reliably indentified marine life. Explorers have yet to explore much of the high Arctic Ocean for life. *Source: Ocean Biogeographic Information System (OBIS)*

of a way to chart the closeness or separation among species by correlating their lengthy DNA sequences.

As a physically tangible legacy, the Census bequeaths to future generations curtains of microphones that can identify individuals migrating along thousands of kilometers of routes from California past British Columbia in Canada to Alaska. It demonstrates that fish only 20 centimeters long can carry sonic tags to trace their passage through the curtains. Larger animals can carry biologgers that record the temperature, depth, and other environmental properties as they swim and dive and then report the data via satellite.

The Census helped devise and leaves the legacy of a sonic system that detects the formation, abundance, and coordinated swimming of schools of fish extending over tens of thousands of square kilometers. The Census helped motivate nations to build research vessels so quiet they would not disturb animals or interfere with listening and so stable that DNA sequencers could operate aboard.

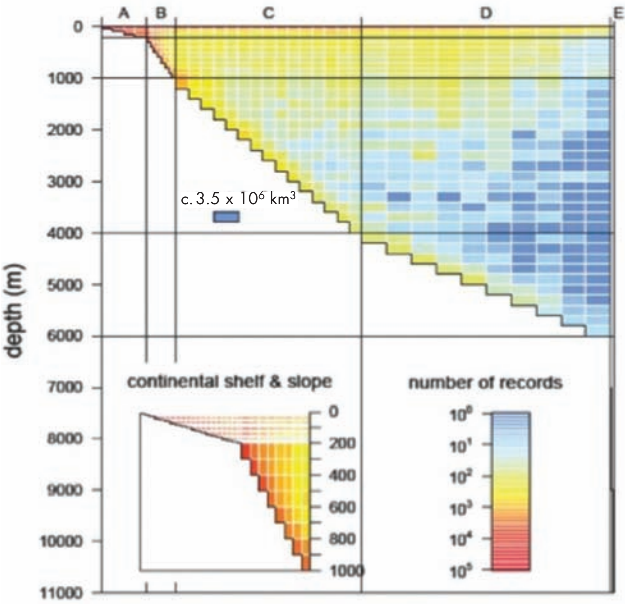
To standardize the global assessment of life on coral reefs and render worldwide analysis of distributions and measurement of change, the Census innovated Autonomous Reef Monitoring Structures. In the same vein, the Census leaves a legacy of standardized methods for appraising marine life near shores and in the deep sea. Taken together, the technologies invented and proven by the Census show that the incipient Global Ocean Observing System, analogous to the system long in operation to monitor the atmosphere, can observe life as well as physical parameters.

Work habits, many good ones, honed during the Census decade will live on and make future global explorations effective. The habit of assembling scientists; choosing a goal like diversity, distribution, and abundance; recruiting more scientists or training new ones; keeping focus on their initial target; and recording their results for all to see—all within a decade—is a legacy for future work. The social networks of experts who span all taxa and oceans and more than 80 nations form a legacy that could speed a second Census and other research programs that societies may value.

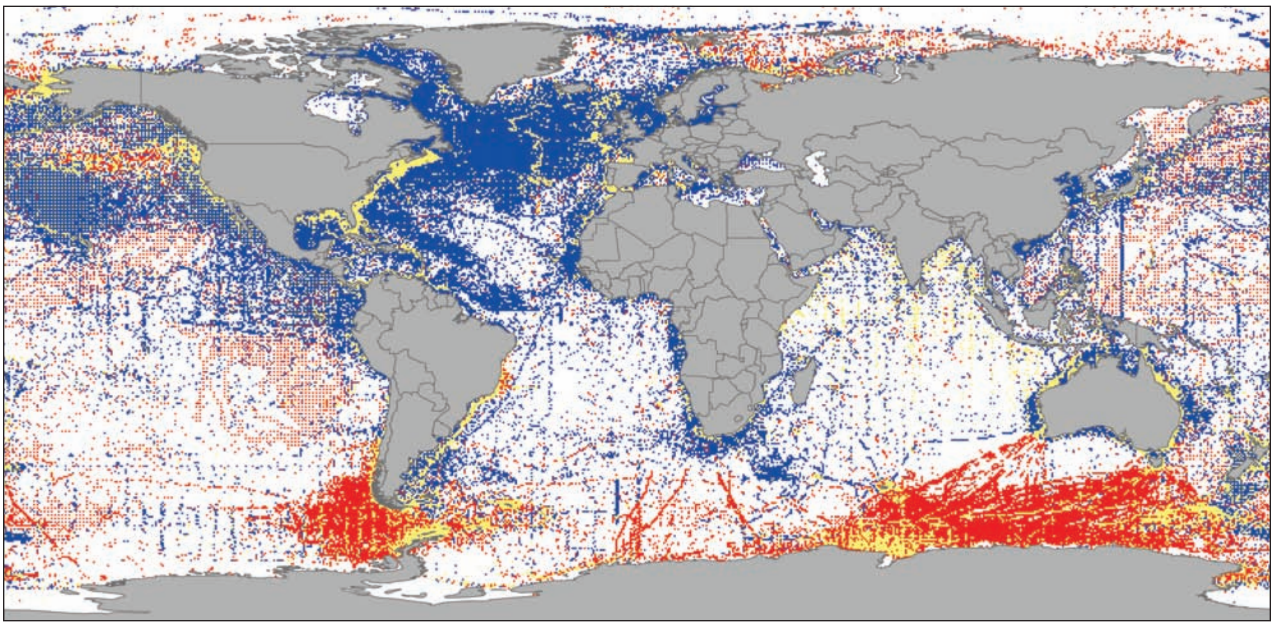
As it worked, the Census sought to establish the habits to identify, systematically, the limits to knowledge and to speak candidly about the unknown and unknowable as well as about what we know. The Census quantified that we know less about the small and showed generally that knowledge is inversely related to size. But some patterns exceed our field of vision, and for these the Census devised macroscopes to overcome limits to knowledge.

The macroscope of OBIS lets everyone see with revolutionary resolution both the known and the unknown ocean. We can see where scientists observed marine life before the Census began and how the Census and other research during the past decade filled in the map. Viewing the density of observations on the surface of the globe shows vast areas in the Eastern Pacific, Southern Ocean, and Arctic, for example, remain almost virgin for exploration for marine life. Viewing a slice of the oceans from the surface to the seafloor beckons explorers to the poorly explored mid-waters.

The Census encountered an ocean growing more crowded with commerce and transparent through technology. Setting out to draw baselines of the diversity, distribution, and abundance of species, the first Census of Marine Life documented a changing ocean, richer in diversity, more connected through distribution and movements, more impacted by humans, and yet less explored than we had known. The Census has multiplied the qualified experts, developed and spread technologies for discovery and monitoring, improved access to data, and informed decisions about conserving marine species and regions. The legacies of the Census—the baselines of knowledge, the cascade of new technology, the collaboration across borders—promise more benefits for humanity and the oceans.



51. OBIS exposes the still-to-be-explored ocean by depth as well as latitude and longitude. On a cross section of the global oceans, the spectrum from red to blue extends from many to few or no records. The records are concentrated near shores and in shallow waters, while the largest habitat on Earth, the vast middle waters, is largely unexplored. *Source: Ocean Biogeographic Information System*



52. A global map of the nearly 30 million OBIS records of 120,000 species from more than 800 datasets shows the known and unknown ocean in half-degree squares by latitude and longitude. In blue areas, the Census has aggregated data from before the Census began and from partner programs and institutions, often assembled by OBIS regional and thematic nodes. Yellow indicates regions with data both from Census partners and from the Census's own expeditions. Red indicates regions with data from Census expeditions where there were no prior data. The records attributable to and supplemented by the Census are numerous in the Southern Ocean, North Pacific, and along the Mid-Atlantic Ridge. Wide regions, such as the Eastern Pacific, remain largely unexplored. *Source: Ocean Biogeographic Information System*

53. *Image: Alison K. Stimpert*

HOW THE CENSUS WORKED

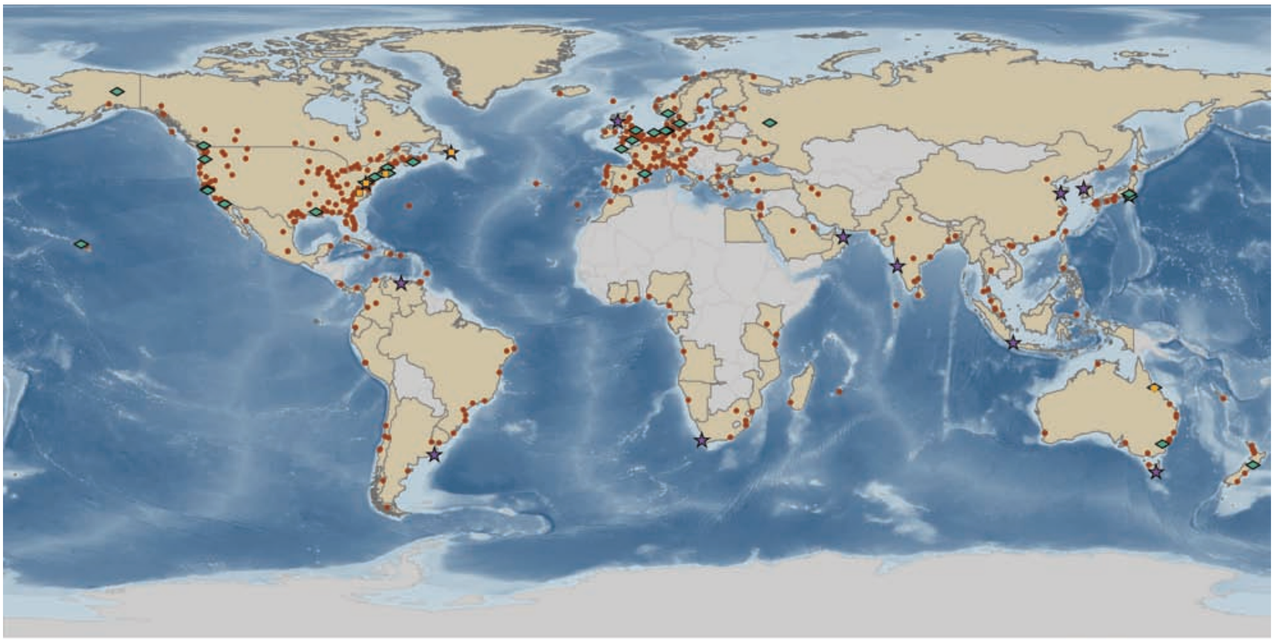
How did the Census work? Agreeing during the 1990s that more was said than done to set a comprehensive and solid foundation of science under the striking scenes and fascinating glimpses beneath the seas, scientists around the globe organized for the first-ever Census of Marine Life. They demonstrated their earnestness by establishing a definite, decadal life for the Census, beginning in the year 2000 and concluding in 2010. They concentrated on learning the diversity (how many different kinds), distribution (where they live), and abundance (how much) of marine life.

To encompass Planet Ocean and engage specialized knowledge about its diverse waters, the Census engaged 2,700 marine scientists from more than 670 laboratories, universities, natural history museums, and aquariums from more than 80 nations and all continents. Three years of discussion and dozens of planning meetings preceded the first expedition flying a Census flag. During the decade, the Census Secretariat at the Consortium for Ocean Leadership in Washington, D.C., coordinated the international network, 66 implementation meetings, and five Census-wide meetings. The Census recognized differing capacities from place to place. Where possible, countries provided ships, funding, and researchers. They gave their intellectual resources, and they opened access to their seas.

Participation grew rapidly in the first half of the decade and continued to grow in the second half. During 9,000 days at sea in more than 540 oceanographic expeditions, Census researchers explored cold, temperate, and tropical seas, from top to bottom and shore to shore. The Scientific Steering Committee of the leaders kept the focus of the Census on global span and on diversity, distribution, and abundance.

Fourteen field projects investigated the major habitats and groups of species in the global ocean to paint a picture of present marine life. Eleven of these projects explored habitats, such as seamounts, vents, and coral reefs. Or they explored regions, such as the Arctic and Southern oceans, the Mid-Atlantic Ridge, or the Gulf of Maine. Three projects surveyed animals, such as the top predator tuna that swim Planet Ocean or small plankton and microbes that drift around the globe.

Two other projects and OBIS completed the roster of Census projects. The first project reconstructed a baseline of past oceans from, for example, old ship logs, monastery records, fish bones, and shell middens. Complementing the reconstruction of the past, another project modeled or projected the effects of variables such as fishing and climate change to anticipate marine life in future oceans. OBIS, the collective data repository, has been described above. National and Regional Implementation Committees provided leadership in 13 regions around the world and extended access to expertise and resources.

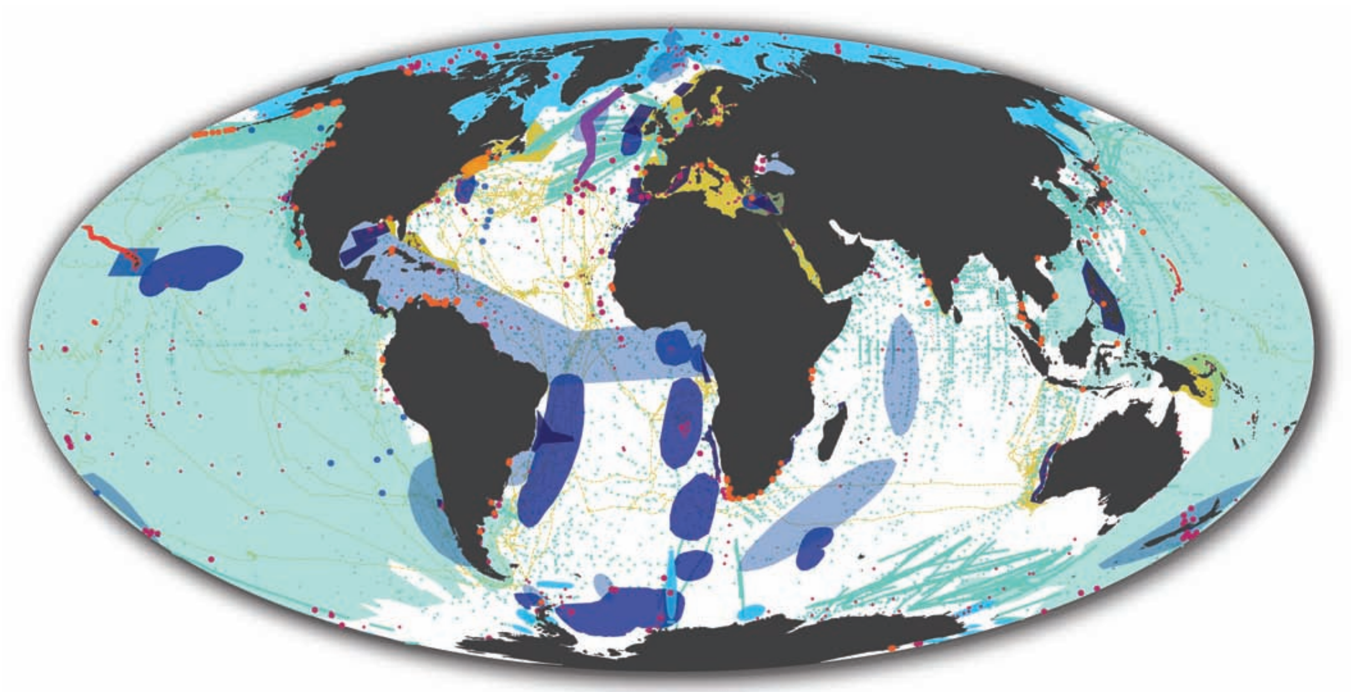


Census of Marine Life global community

Census global coordination | Project headquarters | National or regional headquarters | Participating institution | Participating country

54. Shading shows the global span of 80 plus nations that participated in the Census of Marine Life. The 2,700 scientists participating came from more than 600 institutions and worked in 14 field projects spanning ocean realms from near shore to abyss and latitudes from poles to tropics. The global span of National and Regional Implementation Committees, headquarters of the field projects, and participating institutions such as museums ensured access to expertise and seas. *Image: Census of Marine Life Mapping and Visualization Team*

Census of Marine Life project areas



Coastal
- Regional Ecosystems (GoMA)
- Near Shore (NaGISA)
- Coral Reefs (CReefs)

Polar
- Arctic Ocean (ArcOD)
- Antarctic Ocean (CAML)

Pelagic
- Top Predators (TOPP)
- Continental Shelves (POST)
- Zooplankton (CMarZ)

Deep Sea
- Vents and Seeps (ChEss)
- Abyssal Plains (CeDAMar)
- Seamounts (CenSeam)
- Continental Margins (COMARGE)
- Mid-Ocean Ridges (MAR-ECO)

Global Information and Analysis
- Oceans Future (FMAP)
- Information Systems (OBIS)
- Microbes (ICoMM)
- Oceans Past (HMAP)

55. Census field projects sampled all major zones and realms of the oceans. *Image: Census of Marine Life Mapping and Visualization Team*

The Census of Marine Life Community

GLOBAL LEADERSHIP

Scientific Steering Committee

Ian Poiner, Chair, Australia
Victor Ariel Gallardo, Vice Chair, Chile
Myriam Sibuet, Vice Chair, France
J. Frederick Grassle, Past Chair, USA
Vera Alexander, USA
D. James Baker, USA
Patricio Bernal, France/Chile
D. Chandramohan, India
David Farmer, USA/Canada
Serge Garcia, Italy
Carlo Heip, Netherlands/Belgium
Poul Holm, Ireland/Denmark
Yoshihisa Shirayama, Japan
Michael Sinclair, Canada
Song Sun, China
Meryl Williams, Australia/Malaysia

Past Committee Members

Donald Boesch, USA
Olav Rune Godø, Norway
Andrew Solow, USA

Partners

Encyclopedia of Life
National Geographic
Galatée Films

Projects

Arctic Ocean
ArcOD
Antarctic Ocean
CAML
Mid-Ocean Ridges
MAR-ECO
Vents and Seeps
ChEss
Abyssal Plains
CeDAMar
Seamounts
CenSeam
Continental Margins
COMARGE
Continental Shelves
POST
Near Shore
NaGISA
Coral Reefs
CReefs
Regional Ecosystems
GoMA
Microbes
ICoMM
Zooplankton
CMarZ
Top Predators
TOPP
Oceans Past
HMAP
Oceans Future
FMAP
Global Marine Life Database
OBIS

Affiliated Projects & Collaborators

Marine Barcode of Life
Ocean Tracking Network
Great Barrier Reef Seabed Biodiversity Project
Gulf of Mexico Biodiversity Project
World Register of Marine Species
MarBEF • HERMES
Google Earth • PLoS ONE
Convention on Biological Diversity (CBD)
Scientific Committee on Oceanic Research (SCOR) Technology Panel

GLOBAL PARTICIPATION

National and Regional Implementation Committees

Arabian Sea: Michel Claereboudt, Oman
Australia: Nic Bax
Canada: Philippe Archambault
Caribbean: Patricia Miloslavich, Venezuela
China: Song Sun
Europe: Isabel Sousa Pinto, Portugal
Henn Ojaveer, Estonia
Indian Ocean: Mohideen Wafar, India
Indonesia: Gabriel Wagey
Japan: Katsunori Fujikura
Republic of Korea: Youn-Ho Lee
South America: Diego Rodriguez, Argentina
Sub-Saharan Africa: Charles Griffiths, South Africa
United States of America: Andrew Rosenberg

SYNTHESIZING RESULTS

Synthesis Group

Paul Snelgrove, Chair, Canada
Jesse Ausubel, USA
Darlene Trew Crist, USA
Michele DuRand, Canada/USA
J. Frederick Grassle, USA
Patrick Halpin, USA
Sara Hickox, USA
Patricia Miloslavich, Venezuela
Ron O'Dor, USA/Canada
Myriam Sibuet, France
Edward Vanden Berghe, Belgium
Boris Worm, Germany
Kristen Yarincik, USA

GLOBAL COORDINATION

Secretariat, Consortium for Ocean Leadership, USA
Education and Outreach, University of Rhode Island, Office of Marine Programs, USA
Mapping and Visualization, Duke University, Marine Geospatial Ecology Laboratory, USA

56. Image: Census of Marine Life Education and Outreach Team

Projects affiliated with the Census of Marine Life

The Census extended its reach by affiliation with other projects and programs. It formed a partnership with the National Geographic Society to expand cartographic resources and outreach. The Census Mapping and Visualization Team boosted the creativity and quality of work throughout the program and served as the liaison with National Geographic's cartographers and also with Google Earth, whose ocean layer integrates Census findings.

The Encyclopedia of Life (EOL) is documenting on the Internet all 1.9 million known living species of animals, plants, and fungi. Its infinitely expandable page for each species includes text and also images, graphics, video, and sound. It is compiled from existing databases and from contributions throughout the world. Partnering with EOL, Census scientists helped create Web pages for 80,000 species, which comprise about a third of known marine species. These species in turn come from the master list of another Census partner, the World Register of Marine Species, formed in 2006 to provide in perpetuity an authoritative and comprehensive list of names of marine organisms. A partnership with Aquamaps allows quick creation of standardized distribution maps for species of fishes, marine mammals, and invertebrates in OBIS.

The Census also benefited from the formation in 2004 of the Consortium for the Barcode of Life. The Consortium and the international Barcode of Life initiative aim to offer a reference library of DNA barcodes for more than 500,000 species by the year 2015. The efforts to speed barcodes of marine species operate within the subprograms Marine Barcode of Life Initiative (MarBOL) and Fish Barcode of Life Initiative (FISHBOL), both headquartered at Ontario's University of Guelph.

Affiliated projects and programs added depth and scope to Census work in Australia's Great Barrier Reef, the Gulf of Mexico, the margins of European seas (HERMES, see below), ecosystem functioning (MarBEF), fisheries science (ICES, PICES, and FAO), seas beyond national jurisdiction (IUCN), and global change (IGBP/DIVERSITAS). Cooperation with the Partnership for Observation of the Global Oceans (POGO), the Scientific Committee on Oceanic Research (SCOR) Technology Panel, Scientific Committee on Antarctic Research (SCAR), the Intergovernmental Oceanographic Commission (IOC), and the Group on Earth Observations (GEO) helped integrate the Census with the development of ocean observing systems.

HERMES: Hotspot Ecosystem Research on the Margins of European Seas
MarBEF: Marine Biodiversity and Ecosystem Functioning, European Union Network of Excellence
ICES: International Council for the Exploration of the Sea
PICES: North Pacific Marine Science Organization
FAO: Food and Agriculture Organization
IUCN: International Union for Conservation of Nature
IGBP-DIVERSITAS: International Geosphere-Biosphere Programme Initiative for Biodiversity

During the final four years of the Census, a Synthesis Group continually integrated results and prepared for the culminating events of the Decade of Discovery. The Synthesis Group worked closely with a Mapping and Visualization Team that provided advice and solved problems for all Census teams and projects.

Census scientists tagged 41 species of animals. The 23,000 animals carrying instruments might be added to the 2,700 humans who participated in the Census.

Between 2000 and 2010, by an accounting that incorporates national expenditures on existing fleets, labs, and staff that collaborated as well as activities that occurred only because of the existence of the Census, the program spent US$650 million. Support came from scores of government agencies as well as private foundations, companies, and individuals. From conception, the Alfred P. Sloan Foundation of New York City provided indispensable core support totaling about US$75 million.

For its expenditure on the Census, the world received a stream of knowledge throughout the decade. Census scientists reported progress in more than 2,600 scientific peer-reviewed publications. The Census strongly favored free, open-access Internet publication, which took off during the latter years of the program. An increasing number of Census papers are appearing in the biodiversity hub of the Public Library of Science, which has also established flexible, growing collections of papers for many Census projects and themes.

Five books added to the reports. At the end of the Census decade in 2010, one book gave the public an overview of insights from the Census, their implications, and a glimpse of marine life still unknown.

- *Discoveries of the Census of Marine Life: Making Ocean Life Count,* Paul V.R. Snelgrove, Cambridge University Press, 2010.

A second book summarized the findings and discoveries of the 17 Census projects for scientists with a chapter from each project.

- *Life in the World's Oceans: Diversity, Distribution, and Abundance,* Edited by Alasdair D. McIntyre, Blackwell Publishing, Ltd., 2010.

A third, extensively illustrated book profiled Census research and findings through early 2009 to a public audience.

- *World Ocean Census,* Darlene Trew Crist, Gail Scowcroft, and James M. Harding, Jr., Firefly Books, UWA Publishing, 2009.

57. Research along the Mid-Atlantic Ridge inspired Norwegian Anne Berg Edvardsen's sculpture *Spikes*. Made of paper and clay and about 40 by 40 centimeters, the sculpture suggests an animal trying to lift itself, maybe to change direction. *Image: Anne Berg Edvardsen*

58. The Census inspired the public to examine marine life, too. *Image: Megan Moews*

59. As marine creatures helped the Census by measuring their environment with electronic tags, so too did their form and color help the Census catch the interest of the public. The incongruity of the hairy Kiwa hirsuta that suggested its nickname yeti crab has broad appeal and prompted many to capture its magic, including skateboarders in search of a wild ride. *Image: Nathalie Roland*

A fourth book presented portraits of about a hundred species.

- *Citizens of the Sea: Wondrous Creatures from the Census of Marine Life,* Nancy Knowlton, National Geographic, 2010.

A fifth book portrayed a major expedition examining life and environment in the middle of the North Atlantic from the surface to the floor of the sea.

- *Life in the Mid Atlantic,* Peter Boyle, Bergen Museum Press, 2009.

These and other books formed part of the Census education and outreach effort, which also included Web sites, video and still photographs, museum exhibits, and other products tailored for a range of audiences and stakeholders. The Census reached out early to artists, including photographers, cinematographers, painters, sculptors, and musicians to invite them to participate in the Census and share their own observations of the marine life the Census encountered. Every Census project designated an education and outreach liaison, and a team based at the University of Rhode Island coordinated the network. The Rhode Island team also took responsibility for popular summaries of initial knowledge in 2003 and highlights in 2004, 2005, 2006, and 2008.

60. In a notably fruitful collaboration, the Census lent support to Galatée Film Productions to photograph the film *Oceans* at 54 locations, globally distributed. Census scientists helped conceive the film and ensure its scientific accuracy, and co-authored with Galatée an illustrated guide with taxonomic information about all the species in the film. In return, Galatée provided still images and more than 400 hours of film for Census researchers to study animal behavior in situ.
Image: François Sarano


61. *Image: Gary Cranitch*

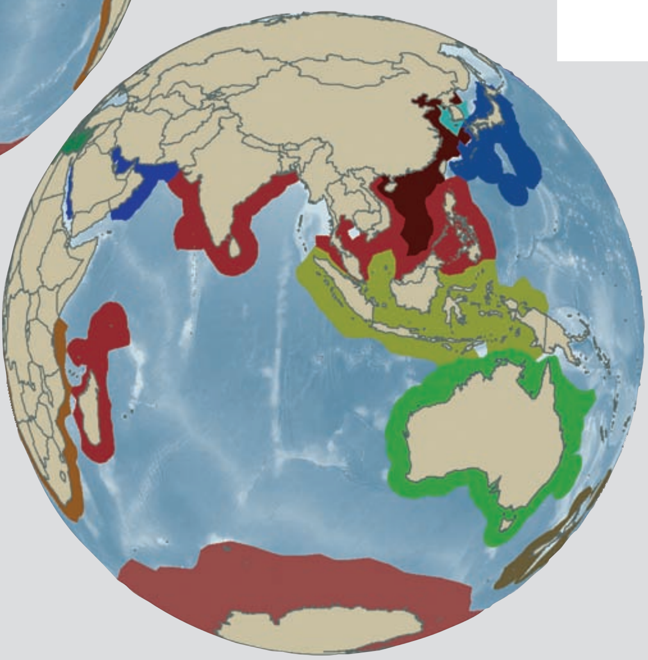
THE CENSUS TEAMS

To inventory life in Planet Ocean, its diversity, distribution, and abundance, the Census had a big job. It had to span all oceanic realms, from coasts down slopes to abyss, from the North Pole across tropics to the shores of Antarctica. It had to encompass giant animals and hidden and almost invisible life, rare individuals and immense schools. It had to range from the long past to the future. It had to compile information from new discoveries and historical archives and make it freely accessible.

National and Regional Implementation Committees began the Census strategy of encompassing the world. Field projects in Arctic and Antarctic seas and along a ridge that connected them ensured exploration from pole to pole. Others explored the vents on ridges, the abyssal plains between ridges and continents, and seamounts that interrupt the plains. Projects explored the continental margins and also the water near shores and reefs. A project in the Gulf of Maine spanned tidal pools, the shelf, and the margins and even touched the nearest seamounts. Other projects examined the ubiquitous microbes, drifting plankton, and swimming top predators that connect the oceans. One project delved into the history of marine life, and another projected its future. A global system made all past and expanding names, addresses, and circumstances of marine life universally available as a baseline for measuring change.

NRICS

National and Regional Implementation Committees extended the reach of the Census of Marine Life globally. Over 360 scientists combined centuries-old information with new Census observations and databases into a roll call of species in representative regions from the Antarctic through temperate and tropical seas to the Arctic. About a fifth of all known, named species were crustaceans, which, with mollusks and fishes, make up half of the roll call. The unprecedented geographical and taxonomic integration showed how collaboration between developed and developing countries expedites discovery.



62. National and Regional Implementation Committees of the Census applied their expertise about nearby waters to compile a roll call of known species, estimated unknown species, and ranked threats to diversity. The numbers of species, the currency of diversity, ranged up to 33,000 in Australian and Japanese waters. Even in familiar waters, undiscovered species and microbes will swell the future number.
Image: Census of Marine Life Mapping and Visualization Team

ArcOD

The **Arctic Ocean Diversity** project established the baseline of marine life in the region. Its search on, in, and under sea ice, in deep basins, and along continental shelves cataloged more than 7,000 animal species, of which at least 70 are new, plus thousands of microbes. Project researchers documented recent northward extensions of ranges of invertebrate and fish species, and a rising ratio of warm- to cold-water species. Making more than 250,000 records accessible online, the project allows measuring changes in Arctic life caused by humanity and natural forces.

Project Leaders
Bodil Bluhm United States
Rolf Gradinger United States
Russ Hopcroft United States

63. Ian MacDonald, 64. Katrin Iken, 65. Rolf Gradinger, 66. Katrin Iken

67. Deep in the frigid Canada Basin, a remotely operated vehicle of the Arctic Ocean project captured the pictured jellyfish of the genus *Crossota. Image: Kevin Raskoff*

CAML

Coordinating 18 research voyages in the widest-ever survey of the region, the **Census of Antarctic Marine Life** project provided the baseline for marine life in the Southern Ocean and then helped establish the monitoring of its change. The project documented more than 16,500 taxa, including hundreds of new species. The researchers identified a single region of seafloor life under the fastest current on the planet, found colonists from deeper water beneath melting ice shelves, and showed how Antarctic waters may incubate new species.

Project Leaders
Michael Stoddart Australia
Victoria Wadley Australia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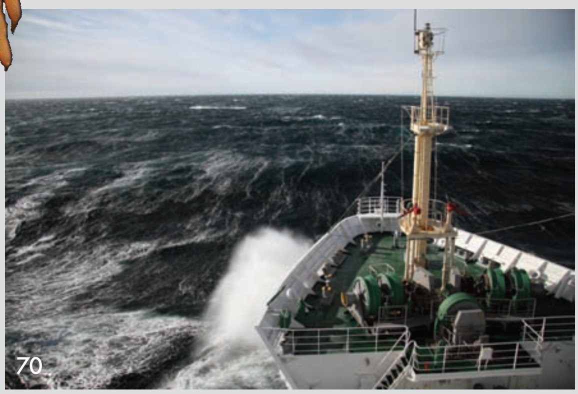
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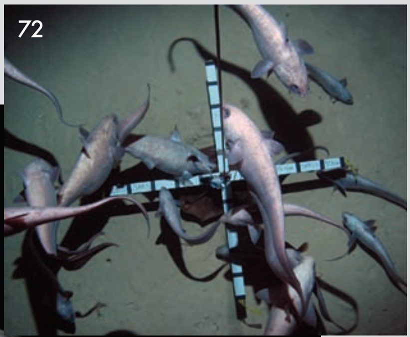
68. Australian Antarctic Division © Commonwealth of Australia
69. *National Institute of Water and Atmospheric Research New Zealand*
70. *Philippe Koubbi*

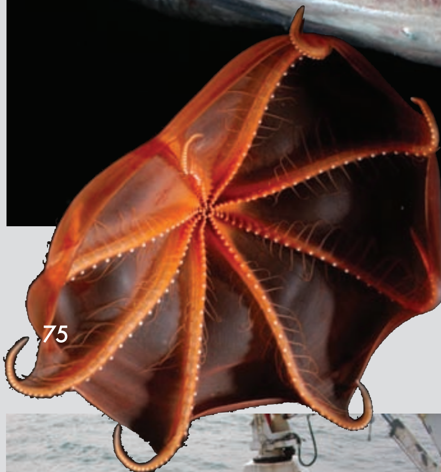
71. In the region of the Polar front near Elephant Island at the tip of the Antarctic Peninsula, scientists investigating the Southern Ocean found the pictured lysianassoid amphipod. The small crustacean encountered during an expedition of the R/V *Polarstern* most likely belongs to both a new species and a new genus. *Image: Cédric d'Udekem d'Acoz*

MAR-ECO

The **Patterns and Processes of the Ecosystems of the Northern Mid-Atlantic** project explored marine life along the world's longest mountain range, which rises from the seafloor 4,500 meters deep. The explorers found approximately 1,000 species, from small crustaceans to whales, including at least 30 new species. They found both mid-water animals from deep basins and bottom-living animals along slopes. Abundance generally peaked where cool and warm waters met. Project findings supported protection of areas of the Mid-Atlantic Ridge against harmful bottom fishing totaling 330,000 square kilometers, larger than Italy.

Project Leader
Odd Aksel Bergstad Norway





72. Nicola King
73 . David Shale
74. Thomas de Lange Wenneck
75. The deep-sea octopod, *Stauroteuthis syrtensis* was photographed in 2004 during the *G.O. Sars* expedition. It measures 13 cm x 8 cm, about the size of a grapefruit. Image: David Shale
76. Klokkargaardens Film AB
77. Thomas de Lange Wenneck
78. David Shale

78

ChEss

The **Biogeography of Deep-Water Chemosynthetic Ecosystems** project explored life at seeps, vents, and whale falls, where fluids cool, hot, corrosively acidic or rich in natural oils nourish marine life. Here, abundant life thrives, fueled by chemical reactions rather than sunlight. Using advanced robots, the project extended the known limits to such life—farther north (72° N) and farther south (60° S), deeper than 4,900 meters and hotter than 407°C. Project scientists described about 200 new species, bringing to more than 1,000 the number of described species known to live without the sun's energy.

Project Leaders

Paul Tyler United Kingdom
Maria Baker United Kingdom
Chris German United States
Eva Ramirez-Llodra Spain

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83



84

79. Craig Smith
80. MARUM, University of Bremen
81. Daichi Fujita
82. MARUM, University of Bremen
83. Anders Warren

84. In the hot and sulfurous water from a vent in the Pacific-Antarctic Ridge in the South Pacific, explorers of vents and seeps found *Kiwa hirsuta* and named it after the goddess of shellfish in Polynesian mythology. Because its hairy appearance suggests the abominable snowman, it has become known as the "yeti crab."
Image: Ifremer/Alexis Fifis

CeDAMar

The **Census of the Diversity of Abyssal Marine Life** project explored the abyssal plains of major ocean basins, particularly the southern Atlantic and the Southern Ocean, described more than 500 new abyssal species from unicellular animals to large squid, investigated the feeding of abyssal organisms, and mapped the distribution of deep-sea life. The project compiled data for establishing protected seafloor outside national jurisdiction and documented that climate change, human debris, and seabed mining affect abyssal life.

Project Leaders
Pedro Martinez Arbizu Germany
Craig Smith United States


85


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87

90


88


89

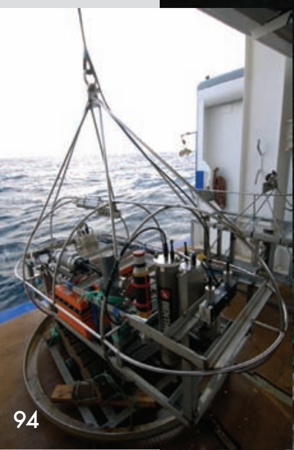
85. Myriam Schueller
86. Wiebke Broekeland
87–88. Brigitte Ebbe
89. Wiebke Broekeland

90. The tiny copepod *Ceratonotus steiningeri*, about three or four times as long as a hair is wide, was found in the Angola Basin.
Image: Jan Michels

CenSeam

The sphere of the **Global Census of Marine Life on Seamounts** project encompassed up to 100,000 seamounts rising 1,000 meters or more from the seafloor. The project discovered new seamounts, species, and communities and found that seamount inhabitants broadly resemble those on adjacent continental slopes. Yet, owing to isolation and slow growth of deep animals, life on seamounts can struggle to recover from disturbances such as fishing. The project's central repository of global seamount data is informing international negotiations about protecting areas in the high seas.

Project Leaders
Malcolm Clark New Zealand
Mireille Consalvey New Zealand
Ashley Rowden New Zealand
Karen Stocks United States



91. The variety that seamounts contribute to ocean topography can also contribute to its biodiversity. In the photograph, a bright orange brisingid sea star is prominent among corals on a seamount. The sea star is feeding by raising its arms to capture passing food from the Antarctic Circumpolar Current. *Image: National Institute of Water and Atmospheric Research (NIWA), New Zealand.*

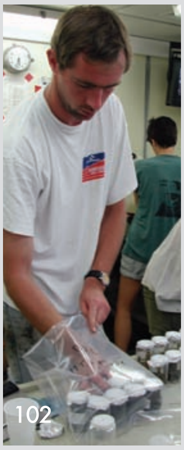
92. *Peter Marriott*
93–95. *NIWA*
96–98. *Global Census of Marine Life on Seamounts*

COMARGE

The **Continental Margin Ecosystems on a Worldwide Scale** project explored slopes of all continents during more than 60 expeditions. They found a meager snow of detritus sustained ribbons of life in the mud along slopes and that the greatest diversity occurs at mid-slope. The project found deep-sea coral stretching over 400 kilometers long off Mauretania. Elsewhere, vast mats of microbes lived off seafloor methane. The project documented the sensitivity of continental slopes to global changes and to exploitation of deposits of gas and petroleum.

Project Leaders

Myriam Sibuet France
Robert Carney United States
Lenaick Menot France



99. A close-up photograph of the sea cucumber *Enypniastes* caught at 2,750 meters on the continental margin in the Celebes Sea between Indonesia and the Philippines reveals its mud-filled intestine through its transparent body.
Image: Laurence P. Madin

100. *Joe F. Siebenauller*
101. *Continental Margin Ecosystems on a Worldwide Scale*
102. *Myriam Sibuet*
103. *Matt Kupchik*
104. *Continental Margin Ecosystems on a Worldwide Scale*
105. *Robert S. Carney*

POST

The **Pacific Ocean Shelf Tracking Project** deployed the first continental-scale array to track marine animals acoustically, and followed juvenile salmon thousands of kilometers from river to ocean, estimated survival of some ocean-migrating salmon stocks, and discovered surprisingly vast migrations of sturgeon across national boundaries. With an expanding library of 16,000 tracks from 18 different species from salmon to jumbo squid, the project built a clearinghouse for sharing telemetry data, contributed to the designation of critical habitat for threatened green sturgeon, and served as a prototype for the global Ocean Tracking Network.

Project Leader
James Bolger Canada/United States

Past Leaders
George Jackson Australia
Gerry Kristianson Canada
David Welch Canada


107


106


108


109


110

106. With acoustic tags implanted in five species of young Pacific salmon and detected by curtains of receivers along the coast, scientists reconstructed the direction, speed, and timing of migrating individuals. Signals from fish like those in the photograph showed the coastal regions and seasons that either favor or discourage survival. *Image: Galatée Films*

107–108. *Pacific Ocean Shelf Tracking Project*
109. *Melinda Jacobs*
110. *Fraser River Sturgeon Conservation Society*

NaGISA

The **Natural Geography in Shore Areas** project initiated the first global nearshore biodiversity inventory, sampling in seagrass beds and rocky shore communities using a standardized protocol to establish baseline information and long-term monitoring of nearshore sites. The project sampled over 200 sites and set up more than 40 long-term sites. It discovered new species and recorded species and habitats where they had not been previously found. Students in Egypt, Greece, Tanzania, the United States, Venezuela, and Japan contributed records to the Census through the project.

Project Leaders
Yoshihisa Shirayama Japan
Brenda Konar United States
Katrin Iken United States
Patricia Miloslavich Venezuela
Juan José Cruz Motta Venezuela
Lisandro Benedetti-Cecchi Italy
Edward Kimani Kenya
Gerhard Pohle Canada


111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112


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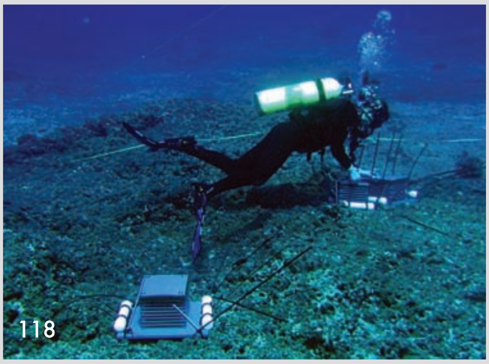
111. Alaskan scientists studying the near shore photographed this *Nereocystis,* a marine alga commonly referred to as bull kelp. Near the shore and in shallow gulfs of the Pacific coast of North America, *Nereocystis* forms kelp forests on beds of rock. It can grow 70 meters long from a root-like holdfast of about 40 centimeters. *Image: Brenda Konar*

112. *Tohru Iseto*
113. *Ana Karinna Carbonini*
114. *Hyakubun Harada*
115. *Susan Ryan*
116. *Iacopo Bertocci*

cReefs

The **Census of Coral Reef Ecosystems** project partnered to conduct the largest concerted exploration of life in the world's coral reefs. It discovered thousands of likely new species and familiar species in new places as well as highly diverse unidentified species in tiny samples of dead coral heads. The project developed a standardized tool, the Autonomous Reef Monitoring Structure (ARMS), to compare distributions of species on reefs as well as monitor changes such as warming and acidification. The 600 ARMS now deployed will reveal global patterns in uniform, standardized data.

Project Leaders
Nancy Knowlton United States
Russell Brainard United States
Julian Caley Australia



117. On a coral reef off northeastern Australia, near what Captain Cook named Lizard Island in 1770 for its many lizards, Census researchers collected this new octopus in an Autonomous Reef Monitoring Structure at a depth of 10–12 meters. The specimen is believed to be a new species. *Image: Julian Finn*

118. *Russell Moffitt*
119–121. *Megan Moews*
122. *Susan Middleton*

GoMA

Spanning tidal pools to seamounts, the **Gulf of Maine Area** project assembled more than 4,000 species in a new register and estimated abundance and diversity of microbes. Analyses showed that habitat explains about a third of variation in distribution and abundance of fishes and invertebrates. New sonars created instantaneous, continuous views of species distributions, including the assembling and swirling of shoals of millions of herring. The novel census of a large area helps managers consider not just one species at a time but an entire marine ecosystem.

Project Leaders
Sara Ellis Canada/United States
Lewis Incze United States
Peter Lawton Canada

Past Leaders
Ken Foote United States
Evan Richert United States

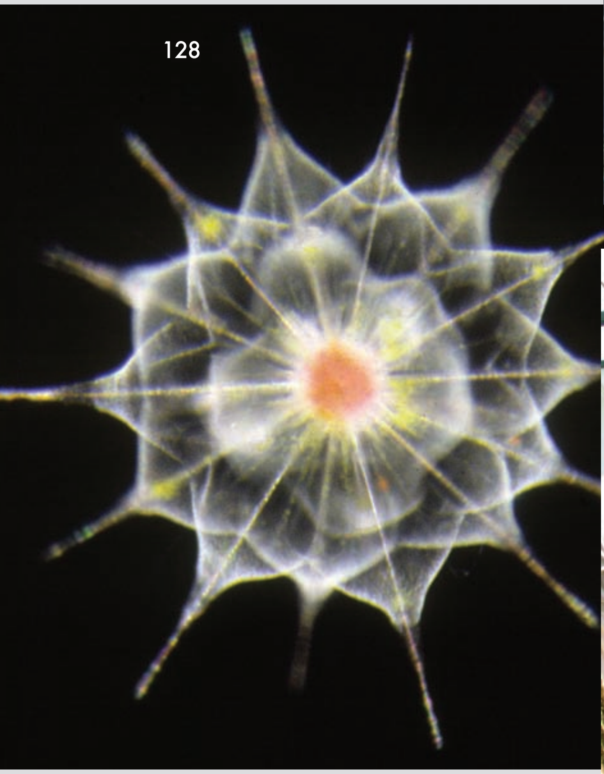
123. The 4,000 plus species in the Gulf of Maine searchable register include the pictured sea star, *Solaster endeca,* found along the shore of Cobscook Bay, Maine. The Census project found twice as many species and thus greater biodiversity in the Gulf than previously estimated. *Image: Christina Kulfan*

124. *Susan Ryan*
125. *Peter Stevick*
126. *Jon Witman*
127. *Kelly Bentham*

ICoMM

In the **International Census of Marine Microbes,** microbiologists from 25 countries determined the range of genetic diversity, distribution, and abundance of oceanic microbes. The investigators found diversity at least 10 to 100 times the previous estimate. A liter of seawater contained about 38,000 kinds of bacteria. In more than 1,200 widely distributed marine samples from water, sediment, and around animals, researchers found some microbes live everywhere, while others live in only a few places. They discovered a "rare biosphere" in which rare microbes account for most ocean diversity.

Project Leaders
Mitchell Sogin United States
Jan de Leeuw Netherlands
Linda Amaral-Zettler United States



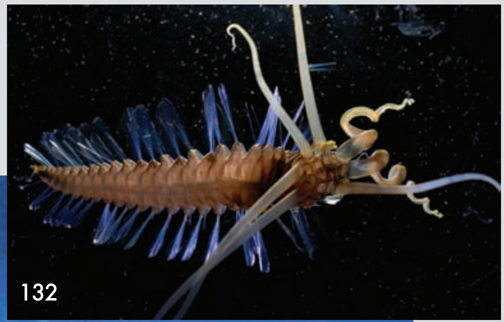
128. The acantharians are one of the four types of large amoebae (microbial eukaryotes) known to occur in marine open waters. The 2-millimeter-wide specimen, about the size of a flea, was captured off Bermuda.
Image: Linda Amaral-Zettler

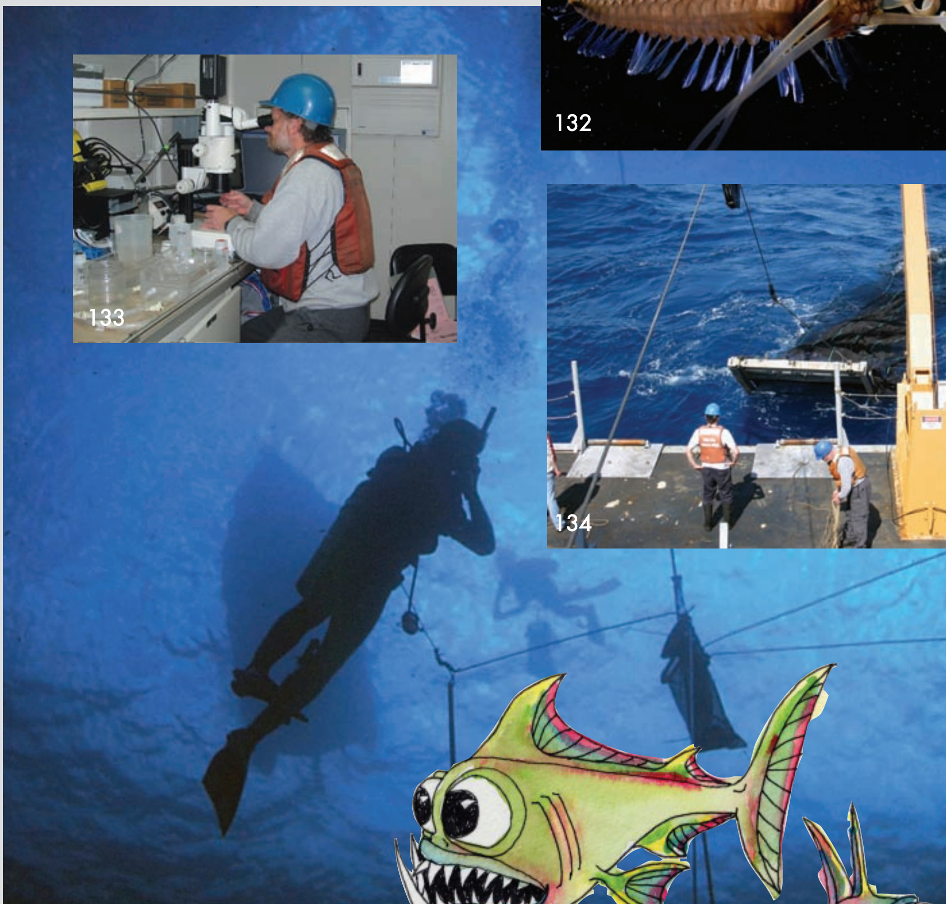
129. *Carola Espinoza*
130. *MOVIE*
131. *Victor Gallardo*

CMarZ

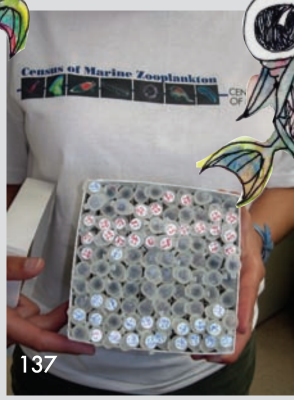
The **Census of Marine Zooplankton** project produced a global view of diversity and distribution of holozooplankton, the animals that drift in ocean currents throughout their lifespan. Researchers collected more than 10,000 samples from every ocean basin. Training 250 new taxonomists, they discovered more than 85 new species, 7 new genera, and 2 new families, many of which are already formally described. They used genetic profiles to develop characteristic fingerprints for all the zooplankton life in any volume of water.

Project Leaders
Ann Bucklin United States
Shuhei Nishida Japan
Sigrid Schiel Germany





136



132. When U.S. and Filipino zooplankton scientists searched the Celebes Sea for new species in its deep water, they discovered and temporarily named this worm, about 10 centimeters long with tentacles, squidworm. One of the small animals that floats or swims weakly, the squidworm turned out to be a new species of polychaete in the class of annelid worms.
Image: Laurence P. Madin

133. *M.D. Allison*
134. *Nancy Copley*
135. *Laurence P. Madin*
136. *Bruce Cowden*
137. *M.D. Allison*

TOPP

The **Tagging of Pacific Predators** project tagged and tracked 4,300 marine predators of 23 species on their journeys. Electronic signals from tags relayed to satellites and on to researchers—and sometimes to the public—displayed animals spanning entire oceans, moving from the poles to the tropics and from continent to continent. Other tags electronically measured and logged characteristics of the surrounding water as the animals swam and dove. Tagged animals frequently migrated along corridors to ocean “hot spots,” where many individuals—and multiple species—congregate for extended periods.

Project Leaders
Barbara Block United States
Steven Bograd United States
Daniel Costa United States
Randy Kochevar United States

Past Leaders
John Gunn Australia
Geoff Arnold Australia

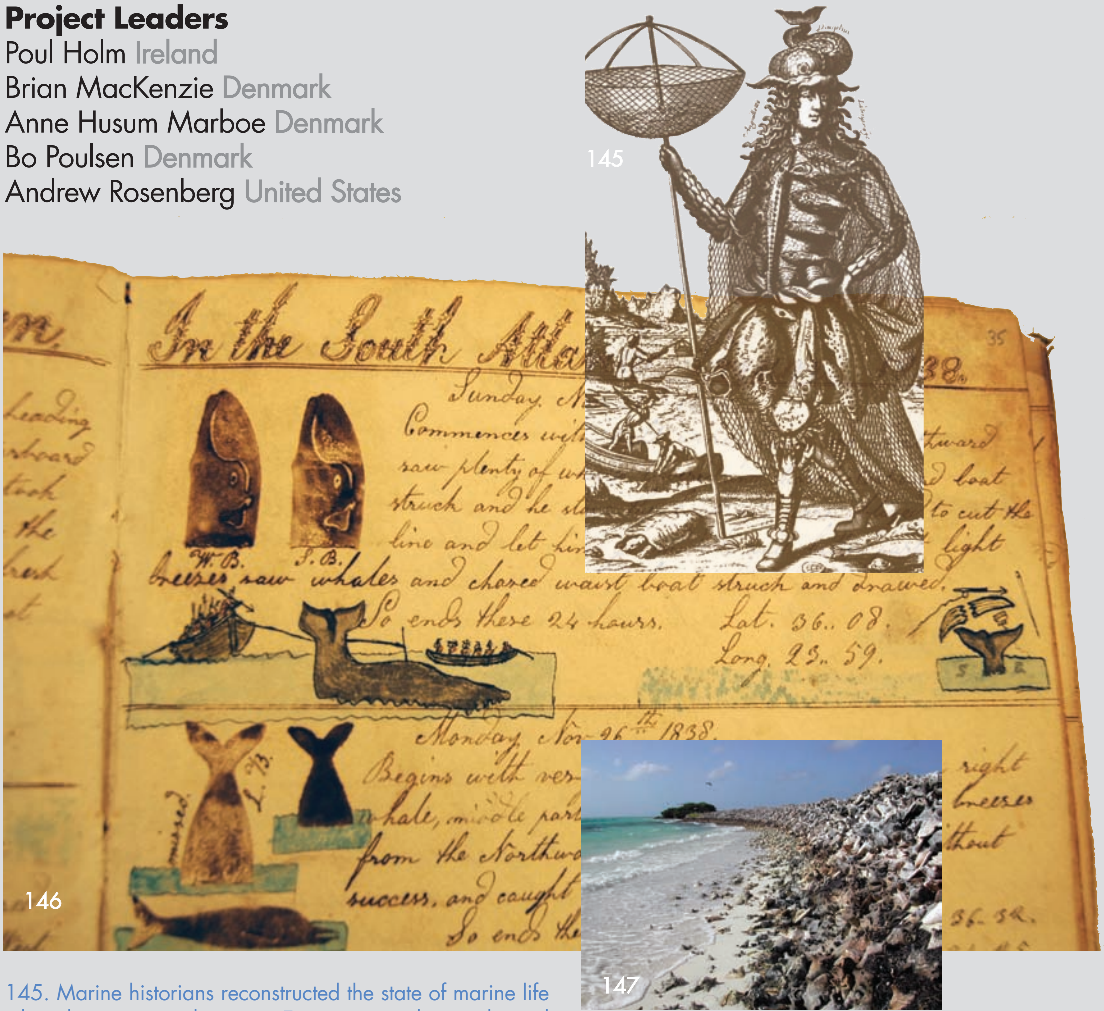
138. As bluefin tuna, *Thunnus thynnus,* traveled, their electronic tags recorded their journeys for researchers studying top predators. In all, 23 species were tracked feeding, mating, and migrating in the Pacific. *Image: Richard Hermann*

139. *Josh Adams*
140–143. *Tagging of Pacific Predators*
144. *Daniel Costa*

HMAP

Studying old and even ancient artifacts and archives, the systematic collaboration between humanities and sciences of the **History of Marine Animal Populations** project found evidence of how humanity and nature change marine life. The utility of the evidence for managing ocean life established the discipline of marine environmental history. Shell jewelry, mosaics, records of taxation on fishing boats, whaling logs, and menus revealed changing marine life and its causes—sometimes storms, sometimes climate, and especially, human harvest of animals and destruction of habitats.

Project Leaders
Poul Holm Ireland
Brian MacKenzie Denmark
Anne Husum Marboe Denmark
Bo Poulsen Denmark
Andrew Rosenberg United States



145. Marine historians reconstructed the state of marine life when this seventeenth-century European gentleman dressed to go fishing. From past states and the present, the scientists assessed the changes caused by human and natural forces. *Detail of a print by Nicholas DeLarmessin*

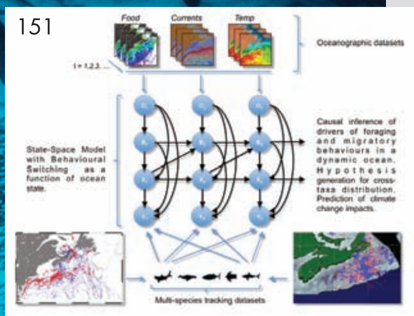
146. *History of Marine Animal Populations*
147. *Andrzej Antczak*
148. *Pieter Bruegel the Elder*

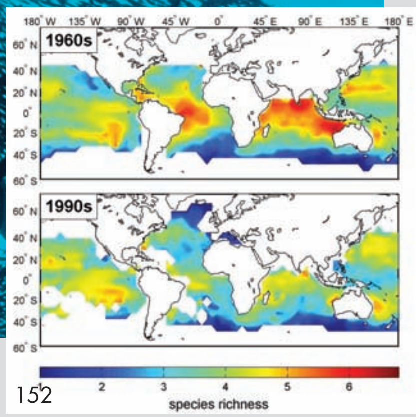
FMAP

The **Future of Marine Animal Populations** project advanced tools for analyzing data from fishing and scientific surveys to determine changes in diversity, distribution, and abundance. Researchers used the entire Census database to define hot spots of diversity and to estimate undiscovered species. They identified the importance of water temperature in shaping diversity patterns and ways climate change might redistribute marine life. They documented how overexploitation caused rapid population declines and conservation helped recoveries. They uncovered patterns of animal movements that showed where animals tend to concentrate when feeding.

Project Leaders
Ian Jonsen Canada
Heike Lotze Canada
Boris Worm Canada

Past Leader
Ransom A. Myers Canada





149. Sharks prey on circling fish near Cocos Island in the eastern tropical Pacific. While marine life thrives in some areas, large predators are threatened across much of their ranges. To project future marine life, scientists analyzed large sets of observations of past populations of a range of animals, including sharks. From the historical baselines that they established, they saw many declines and a few recoveries of numbers. *Image: © Bob Cranston*

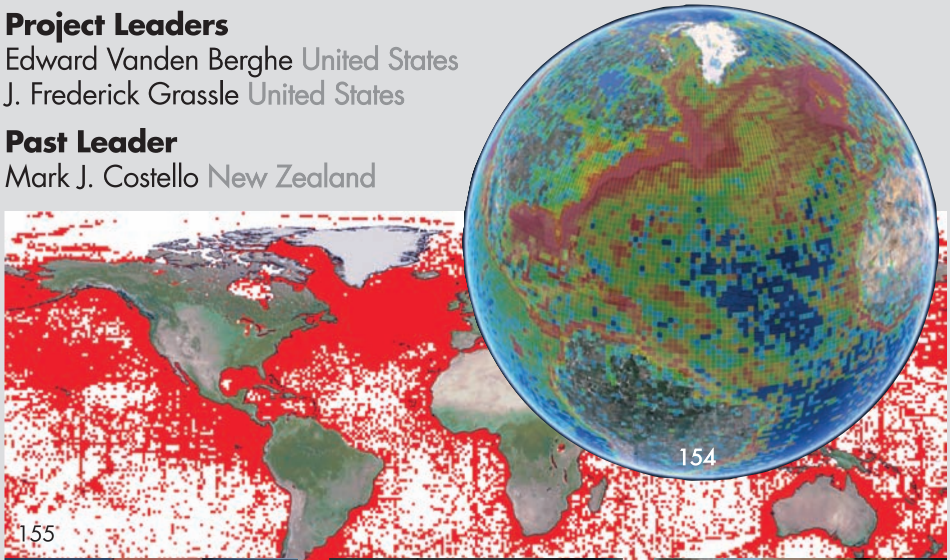
150. *Boris Worm*
151. *Future of Marine Animal Populations*
152. *Boris Worm,* et al.
153. *Alexandra Morton*

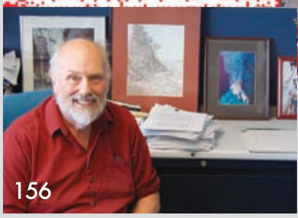
OBIS

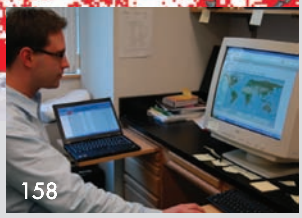
The **Ocean Biogeographic Information System** (OBIS), built by the Census, forms the world's largest online repository of spatially referenced marine life data. Its present nearly 30 million records from more than 800 datasets locate species from *Aaptolasma americana* to *Zyzzyzus warreni* in all parts of the world's oceans in an evolving but permanent repository. It identifies diversity hot spots and broad patterns, tracks dispersion of species, and integrates species locations with temperature, salinity, and depth. Online, it instantaneously maps the distribution of specimens of a species.

Project Leaders
Edward Vanden Berghe United States
J. Frederick Grassle United States

Past Leader
Mark J. Costello New Zealand







154. Maps of all observations in the Census database show the known and unknown ocean. A map centered on the Atlantic displays the general state: Observations are most numerous near surface, near shore, and near or between rich nations. Wide expanses await exploration. *Image: Ocean Biogeographic Information System*

155. *Ocean Biogeographic Information System*
156–157. *Brook Herlach*
158. *Edward Vanden Berghe*
159. *Ocean Biogeographic Information System*
160. *Edward Vanden Berghe*

PHOTO CREDITS & IMAGE SOURCES

1–2. Census of Marine Life Mapping and Visualization Team

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7. Gary Cranitch, Queensland Museum, Brisbane

8. Jim Toomey, www.slagoon.com

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"Marine fish diversity: History of knowledge and discovery."
Zootaxa, 2525: 19–50, 2010

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Philippe Bouchet and Benoit Fontaine,
Muséum national d'Histoire naturelle, Paris

13. Roberto Danovaro, University of Ancona, Italy

14. Andrew J. Gooday, National Oceanography Centre, Southampton, United Kingdom

15. David Shale, www.deepseaimages.co.uk

16. Cindy Lee Van Dover, Duke University Marine Laboratory, North Carolina

17. Microbe: Anna-Louise Reysenbach, *et al.* Adapted by permission, Macmillan Publishers Ltd. *Nature,* 442 (7101): 444–447, 2006. Vent: Anna-Louise Reysenbach and Woods Hole Oceanographic Institution, Massachusetts

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20. Max K. Hoberg, Institute of Marine Science University of Alaska Fairbanks

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22. From top: Russ Hopcroft, University of Alaska Fairbanks
Gary Cranitch, Queensland Museum, Brisbane
Colomban de Vargas © EPPO/SB Roscoff, France
Julian Finn, Museum Victoria, Melbourne
Gary Cranitch, Queensland Museum, Brisbane
Larry Madin, Woods Hole Oceanographic Institution
John Huisman, Murdoch University, Perth
Katrin Iken, University of Alaska Fairbanks
Bernard Picton, National Museums of Northern Ireland
Piotr Kuklinski, Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

23. Barcode: Mark Stoeckle, Rockefeller University, New York. Images: Cheryl Clarke-Hopcroft, Russ Hopcroft, Bodil Bluhm, and Katrin Iken, University of Alaska Fairbanks

24. Dirk Steinke, University of Guelph, Ontario

25. Bodil Bluhm, University of Alaska Fairbanks

26–27. Ocean Biogeographic Information System (source) Encyclopedia of Life (image)

28. Harte Research Institute, Texas A&M University Corpus Christi

29. Pacific Ocean Shelf Tracking

30. Southern Ocean Seals as Oceanographic Samplers, University of St. Andrews, Scotland (source), Daniel Costa (image)

31. Daniel Costa, Tagging of Pacific Predators

32. Image from "Habitat utilization of the Gulf of Mexico by bluefin and yellowfin tuna," Teo and Block, PLoS ONE, 2010

33. Salvador Jorgensen, *et al., Proceedings of the Royal Society B: Biological Sciences,* 277 (1682): 679

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35. Patterns and Processes of the Ecosystems of the Northern Mid-Atlantic project

36. Daniel Costa. Courtesy of the U.S. Antarctic Marine Living Resources Program, Southwest Fisheries Science Center, La Jolla, California

37. Mark J. Costello, University of Auckland, New Zealand

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53. Alison K. Stimpert, Duke University, North Carolina

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57. Anne Berg Edvardsen, www.anne-b-edvardsen.com

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59. Nathalie Roland, www.headphonerecord.com/Nathalie_Roland/welcome.html

60. François Sarano, Galatée Films

61. Gary Cranitch, Queensland Museum, Brisbane

62. Census of Marine Life Mapping and Visualization Team

ArcOD

63. Ian MacDonald, Florida State University. Scientists and crew of the U.S. Coast Guard Cutter *Healy* stand on the ice in the Canada Basin of the Arctic Ocean.
64. Katrin Iken, University of Alaska Fairbanks. Diver photographs fauna below the ice of the central Arctic.
65. Rolf Gradinger, University of Alaska Fairbanks. Helicopter view of the *Healy*.
66. Katrin Iken, University of Alaska Fairbanks. Diver surfaces after a dive under Arctic sea ice.
67. Kevin Raskoff, Monterey Peninsula College, California

CAML

68. Australian Antarctic Division, © Commonwealth of Australia. Revealed by the powerful lights of a trawl-mounted camera, these elegant solitary sea squirts, or tunicates, stand half a meter high on the seabed, 200 meters below the surface of the sea off Terre Adélie. They were photographed during the Collaborative East Antarctic Marine Census (CEAMARC) voyage to the Southern Ocean in 2010. Solitary sea squirts are fast growing, early colonizers that take advantage of new habitat created by icebergs scouring the seabed.
69. National Institute of Water & Atmospheric Research (NIWA) New Zealand, 2007. Census researchers on R/V *Tangaroa* hold giant Macroptychaster sea stars.
70. Philippe Koubbi, Institut Paul Émile Victor and Centre national de la recherche scientifique. The Japanese research vessel R/V *Umitaku Maru* participated with two other vessels during the International Polar Year 2007/08 in the CEAMARC voyage to study life in the waters off East Antarctica.
71. Cédric d'Udekem d'Acoz, Flanders Marine Institute, Oostende, Belgium

MAR-ECO

72. Nicola King, Oceanlab, University of Aberdeen, Abyssal grenadiers, *Coryphaenoides armatus,* were photographed by one of MAR-ECO's ROBIO landers deployed on the Mid-Atlantic Ridge.
73. David Shale, www.deepseaimages.co.uk. A deepwater lizard fish. An ambush predator usually seen sitting motionless on the seafloor.
74. Thomas de Lange Wenneck, Institute of Marine Research, Norway. An orange roughy that is probably more than 100 years old is held by a scientist
75. David Shale, www.deepseaimages.co.uk
76. Klokkargaardens Film AB. Launching of the manned submersible *MIR* to dive to 4,200 meters in the Charlie-Gibbs Fracture Zone, 2003.
77. Thomas de Lange Wenneck, Institute of Marine Research, Norway. Researchers sort a deepwater bottom trawl sample.
78. David Shale, www.deepseaimages.co.uk. After two months aboard Norway's state-of-the-art R/V *G.O. Sars,* 60 scientists from 13 countries returned from the Mid-Atlantic Ridge with unprecedented quantity and quality of samples and data, impressive video footage captured by robotic submersibles, sonar data showing deep donuts of plankton 10 kilometers in diameter, and photographs of many probable new species among the more than 80,000 specimens collected.

ChEss

79. Craig Smith, University of Hawaii. A 30-ton grey whale was studied with respect to community succession over many years.
80. MARUM, University of Bremen, © 2006. Near a vent 3 kilometers beneath the equatorial Atlantic, Census researchers, using equipment attached to the remotely operated vehicle *Quest*, found shrimp and other life forms. They were found living near a hydrothermal vent billowing chemical-laden water at an unprecedented 407°C, a temperature that melts lead easily. It was the hottest marine temperature ever recorded.
81. Daichi Fujita, Japan
82. MARUM, University of Bremen, The remotely operated vehicle *Isis* withstands crushing pressures and extreme temperatures to study the geology, geochemistry, and biology of hydrothermal vents and cold seeps. Biogeography of Deep-Water Chemosynthetic Ecosystems project
83. Anders Warren, Swedish Museum of Natural History
84. Alexis Fifis, French Research Institute for Exploitation of the Sea

CeDAMar

85. Myriam Schueller, University of Bochum. R/V *Polarstern* in the Southern Ocean.
86. Wiebke Broekeland, Senckenberg Research Institute, Frankfurt. The Epibenthic Sledge coming back with benthic animals from the abyssal seafloor of the Weddell Sea.
87. Brigitte Ebbe, Senckenberg Research Institute, Frankfurt. Large benthic fauna caught with an Agassiz Trawl in the Southern Ocean is being separated from the deep-sea mud.
88. Brigitte Ebbe, Senckenberg Research Institute, Frankfurt. Scientists prepare a box corer for deployment.
89. Wiebke Broekeland, Senckenberg Research Institute, Frankfurt. Scientists process a collected sediment sample.
90. Jan Michels, Senckenberg Research Institute, Frankfurt

CenSeam

91. National Institute of Water and Atmospheric Research, New Zealand
92. Peter Marriott, National Institute of Water and Atmospheric Research, New Zealand, R/V *Tangaroa* about to set sail.
93. National Institute of Water and Atmospheric Research, New Zealand. Orange roughy swimming over a seamount.

94–95. National Institute of Water and Atmospheric Research, New Zealand. Towed cameras, such as the deep-towed imaging system (DTIS) have been used to collect video and photographs of seamount communities.

96. Global Census of Marine Life on Seamounts. The CenSeam Steering Committee, 2008
97. Global Census of Marine Life on Seamounts. In 2008 CenSeam-linked researchers sampled seamounts along the Macquarie Ridge.
98. Global Census of Marine Life on Seamounts. The CenSeam Steering Committee, 2007

COMARGE

99. Laurence P. Madin, Woods Hole Oceanographic Institution
100. Joe F. Siebenauller, Louisiana State University. After towing an otter trawl on the bottom of the Gulf of Mexico for two hours, LSU technician Sean Keenan and ship's crew prepare to remove the sample of deep-sea life onto a pitching deck.
101. Continental Margin Ecosystems on a Global Scale. Attendees at "Towards a Globalization of COMARGE" workshop at the Institut Océanographique, Paris, June 2006
102. Myriam Sibuet, French Research Institute for Exploitation of the Sea. On board the *l'Atlante,* Lenaick Menot handles African margin samples obtained with the ROV Victor 6000.
103. Matt Kupchik, Louisiana State University. Deep sampling proceeds around the clock. A beam trawl is recovered at 0300 from 2,200 meters in the Gulf of Mexico as graduate student Erin Becker and Dr. Bob Carney watch and wait to process the sample of deep-sea life.
104. Continental Margin Ecosystems on a Global Scale. COMARGE Steering Committee meeting, National Museum of Natural History, Smithsonian Institution, Washington, D.C., January 2007.
105. Robert S. Carney, Lousiana State University. Scientist and pilot wait expectedly in the acrylic shpere of the manned submersible Johnson *Sealink* suspended over the ocean while the ship manuvers for a precision launch to 800 meters on the margin of the Gulf of Mexico.

POST

106. Courtesy of Galatée Films. Sockeye salmon, Port Banks, Alaska, USA
107. Pacific Ocean Shelf Tracking project, 2006. A researcher displays a tagged salmon smolt.
108. Pacific Ocean Shelf Tracking project, 2006. Tagged salmon are released into the Pacific Ocean.
109. Melinda Jacobs, Pacific Ocean Shelf Tracking project/ Kintama Research Corporation. Acoustic receivers await final programming before deployment along the Pacific coast of North America.
110. Fraser River Sturgeon Conservation Society. A tagged sturgeon is released by researchers.

NaGISA

111. Brenda Konar, University of Alaska Fairbanks, 2004
112. Tohru Iseto, Kyoto University, 2009. Hua Thai Tuyen collects a sediment core from a seagrass bed in Vietnam.
113. Ana Karinna Carbonini, Universidad Simón Bolívar, Venezuela, 2010. The NaGISA sampling protocols have become teaching tools at several high schools and universities around the world, as students in Venezuela demonstrate.
114. Hyakubun Harada, Kyoto University, 2009. Coastal researchers study bivalve taxonomy at a workshop in Penang, Malaysia.
115. Susan Ryan, University of Southern Maine, 2007. The late Dr. Robin Rigby who was instrumental in integrating nearshore sampling in the Gulf of Maine, prepares quadrats for sampling.
116. Iacopo Bertocci, University of Pisa, 2006. Divers collect subtidal samples from the Mediterranean Sea along the Calafuria rocky coast near Livorno, Italy.

CReefs

117. Julian Finn, Museum Victoria, Melbourne, Australia
118. Russell Moffitt, National Oceanic and Atmospheric Administration (NOAA) Pacific Islands Fisheries Science Center (PIFSC), Papahanaumokuakea, Hawaii, 2008. A NOAA diver installs Autonomous Reef Monitoring Structures (ARMS) at Pearl and Hermes Atoll in the Northwestern Hawaiian Islands.
119. Megan Moews, NOAA PIFSC, Honolulu, Hawaii, 2008. CReef's PI's Nancy Knowlton, Rusty Brainard, and Julian Caley process test ARMS retreived off of the Island of Oahu, Hawaii, during the 2008 ARMS sampling, processing, and molecular development workshop.

120– 121. Megan Moews, NOAA PIFSC, Honolulu, Hawaii, 2009. In 2009, Census scientists launched a "Hands-on-ARMS" outreach effort that targeted elementary and junior high school children, but has since reached over 6,000 people and with plans to make it worldwide.

122. Susan Middleton ©2006, courtesy of Northwestern Hawaiian Islands Marine National Monument. A spectacular anemone hermit crab captured in the French Frigate Shoals off the Northwestern Hawaiian Islands. The shiny gold on its claws is a phenomenon not seen before. Scientists believe it may serve as a form of communication. The crab also has its very own species of anemone attached to its shell (brown, fuzzy area below the shell), which is not known to attach to any other species of hermit crabs. This is but one example of how Census discoveries often pose more questions than they answer.

GoMA

123. Christina Kulfan, Suffolk University, Boston
124. Susan Ryan, University of Southern Maine, 2007. GoMA researchers collect samples along Maine's Cobscook Bay coastline.
125. Peter Stevick, Gulf of Maine Area Program, 2005. Two humpback whales, *Megaptera novaeangliae,* feed on red krill.
126. Jon Witman, Brown University, 2008. Divers retrieve a time-lapse camera from isolated Cashes Ledge.
127. Kelly Bentham, Bedford Institute of Oceanography, Canada, 2010 (with permission from Canadian Scientific Submersible Facility). Ship-board researchers direct a remotely operated vehicle in the Northeast Channel Coral Conservation area.

ICoMM

128. Linda Amaral-Zettler, Marine Biological Laboratory, Woods Hole
129. Carola Espinoza, Universidad de Concepción, Chile. Giant sulfur bacteria inhabit anoxic sediments in the eastern South Pacific.
130. Microbial Oceanography at the University of Vienna (MOVIE). Researchers collect dark ocean seawater for microbial DNA samples during a cruise in the Romanche Fracture Zone (19°W, 0°N) of the equtorial Atlantic.
131. Victor Gallardo, Universidad de Concepción, Chile. Bacterial mats that thrive mostly on hydrogen sulfide were found off the coast of Chile.

CMarZ

132. Laurence P. Madin, Woods Hole Oceanographic Institution
133. M.D. Allison, Woods Hole Oceanographic Institution, 2006. Researcher Russell R. Hopcroft (University of Alaska Fairbanks) aboard the R/V *Ronald H. Brown* photographs live zooplankton.
134. Nancy Copley, Woods Hole Oceanographic Institution, 2006. Zooplankton net heading to 5,000 meters depth, towed by the R/V *Ronald H. Brown* in the Sargasso Sea.
135. Laurence P. Madin, Woods Hole Oceanographic Institution. Bluewater divers silhouetted against the ocean surface. The safety diver (in the foreground) carries a short stick hanging down from his clip to push away curious sharks. The other diver swims with a collecting bag filled with jars to hold small animals. Another bag is clipped to the down-line below the trapeze. The lines on the right side of the photo are clipped to two other divers (not shown).
136. Bruce Cowden, bosun of the R/V *Ronald H. Brown,* 2006. Illustration of three-gilled angry bosunfish.
137. M.D. Allison, Woods Hole Oceanographic Institution 2006. Vials of copepods ready for DNA sequencing.

TOPP

138. Richard Hermann, Galatée Films
139. Josh Adams, Tagging of Pacific Predators. Darren Scott with tagged sooty shearwater.
140. Courtesy of Tagging of Pacific Predators. TOPP whale researcher Bruce Mate returns to the ship.
141. Courtesy of Tagging of Pacific Predators. The TOPP whale taggers returning to the dock.
142. Courtesy of Tagging of Pacific Predators. TOPP scientists at work tagging a bluefin tuna.
143. Courtesy of Tagging of Pacific Predators. A salmon shark is raised onto the boat for tagging.
144. Daniel Costa, University of California, Santa Cruz. A team tags a Northern Elephant Seal.

HMAP

145. Detail of a print by Nicholas De Larmessin.
146. Courtesy of History of Marine Animal Populations. Whaling logbook from November 1838.
147. Andrzej Antczak, Universidad Simón Bolívar, Caracas, Venezuela. Between 1200 and 1500 CE, more than 5 million conchs were harvested leaving this pre-Hispanic megamidden, or shell mound, of queen conch, *Strombus gigas,* on La Pelona Island, Los Roques Archipelago, Venezuela.
148. Pieter Bruegel, the Elder, drawing, Pieter van der Heyden, engraving, *Big Fish Eat Little Fish,* 1557

FMAP

149. © Bob Cranston
150. Boris Worm, Dalhousie University. FMAP researcher performs an underwater transect off the coast of Belize to study the effects of fishing on species richness.
151. Future of Marine Animal Populations. This animal movement diagram shows linking of multiple environmental and tracking datasets to explore animal movement, behavior, and habitat use.
152. Worm, *et al.,* 2005. *Science* 309: 1365–1369. Changes in tuna and billfish species richness over time (expected species per 50 individuals). These long-term declines correlated with increasing pressure.
153. Alexandra Morton. The late Ransom A. Myers near the Ahta River in British Columbia, 2007.

OBIS

154. Ocean Biogeographic Information System, Census of Marine Life Mapping and Visualization Team
155. Ocean Biogeographic Information System. Since 2000, the Ocean Biogeographic Information System has grown to nearly 28 million records of more than 120,000 species from more than 800 datasets. The red dots on the map show the global distribution of OBIS records.
156. Brook Herlach, Rutgers University, New Jersey. J. Frederick Grassle, former chair of the Census of Marine Life Scientific Steering Committee and project leader of OBIS at Rutgers University.
157. Brook Herlach, Rutgers University, New Jersey. William Stafford at work in Rutgers University Institute for Marine and Coastal Sciences, host institute to the international OBIS Secretariat.
158. Edward Vanden Berghe, Rutgers University, New Jersey. Brook Herlach at work in Rutgers University Institute for Marine and Coastal Sciences, host institute to the international OBIS Secretariat.
159. Courtesy of Ocean Biogeographic Information System. The OBIS Governing Board, which met regularly to ensure the integration of worldwide data.
160. Edward Vanden Berghe, Rutgers University, New Jer-sey. Fabio Lang da Silveira, Chair of OBIS' Managers Committee, and Daphne Fautin, head of the OBIS delegation to GBIF, at the eBiosphere conference in London, June 2009.

Mother and calf Weddell seal
Terre Adélie, Antarctica, 2007.
Image: Galatée Films

FIRST CENSUS OF MARINE LIFE 2010 **HIGHLIGHTS OF A DECADE OF DISCOVERY**

Census of Marine Life Projects

Arctic Ocean: **ArcOD**
Antarctic Ocean: **CAML**
Mid-Ocean Ridges: **MAR-ECO**
Vents and Seeps: **ChEss**
Abyssal Plains: **CeDAMar**
Seamounts: **CenSeam**
Continental Margins: **COMARGE**
Continental Shelves: **POST**
Near Shore: **NaGISA**
Coral Reefs: **CReefs**
Regional Ecosystems: **GoMA**
Microbes: **ICoMM**
Zooplankton: **CMarZ**
Top Predators: **TOPP**
Oceans Past: **HMAP**
Oceans Future: **FMAP**
Global Marine Life Database: **OBIS**

National and Regional Implementation Committees

Arabian Sea
Australia
Canada
Caribbean
China
Europe
Indian Ocean
Indonesia
Japan
Republic of Korea
South America
Sub-Saharan Africa
United States of America

CENSUS OF MARINE LIFE

A species first described by Linnaeus in 1758, and a member of a family defined by Charles Darwin in 1852, *Lepas anserifera*, attaches its flexible stalk to floating objects such as driftwood, fishing boats, and plastic bottles. Exemplifying a familiar, cosmopolitan species, the goose barnacle still surprises us with its beauty.

Image: David Shale © 2004

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