AT THE LIMITS OF KNOWLEDGE

Discoveries of record-breaking extremes at the frontiers of knowledge highlighted the year. And six years into its ten-year program, the Census of Marine Life has gone fully global. The 17 core Census projects involve networks of researchers spanning all ocean realms. Affiliated projects added during 2006 in the Gulf of Mexico and along Australia's Great Barrier Reef bring the participants to more than 2,000 from 80 nations. Nine regional and national committees ensure that all areas of the global ocean are represented.

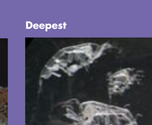
To census the diversity, distribution, and abundance of marine life, participants pooled their talents and specialties, ships and laboratories, archives and technology. They sailed on 19 expeditions, for example, in the Southern Ocean bringing onboard more new species than species already seen by centuries of explorers. Nearshore, the number of active sampling sites has grown exponentially from 30 to 128 in 2006 alone. Across the open ocean, Census participants tracked with satellites more than 20 species of animals from sharks and squid to sea lions and albatross, distributing themselves through hundreds of thousands of kilometers of national and international waters. With sound waves, participants outlined schools of abundant fish spanning tens of kilometers of ocean, whose three dimensions could not be revealed previously by one-dimensional traverses. The now-proven effectiveness of the Census' unprecedented international links, coordination of work, and sharing of data in 2006 point toward a census by 2010 of what lived, now lives, and will live in the world's oceans.

Hottest

ChEss Near a vent 3 km 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 407º C, a temperature at which lead melts easily. It was the hottest marine temperature ever recorded.

MARUM, University of Bremen © 2006.

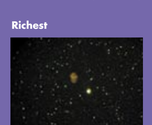
Deepest



CMarZ In a zooplankton trawl 5 km below the surface of the Sargasso Sea, Census experts from 14 nations caught drifting, often menacing looking, animals such as this amphipod, a small prawn-like crustacean, the supposed inspiration for the movie *Alien*. They collected more than 500 species, likely including 12 wholly new species that eat each other or live on organic matter falling like snow from above.

R. Hopcroft, University of Alaska Fairbanks © 2006.

Richest



ICoMM In the sense that biodiversity is richness, Census microbe hunters found a richness of 20,000 kinds of bacteria floating in a single liter of sea water. Samples were taken in the Atlantic and Pacific, including from an eruptive fissure 1,500 m deep. Revealed by DNA studies, most were unknown and likely rare, inviting an estimate that the diversity of bacteria in the oceans eclipses 5 to 10 million.

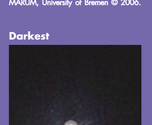
J. Fuhrman, University of Southern California © 2006.

Farthest

TOPP Tracking tagged sooty shearwaters by satellite, Census researchers mapped a small bird's 70,000-km search for food in a giant figure eight over the Pacific Ocean, from Hawaii to New Zealand to Polynesia to Japan and back. Making this longest-ever electronically recorded migration is only 200 days, the bird averaged a surprising 350 km per day. In some cases, a breeding pair made the entire journey together.

TOPP © 2006.

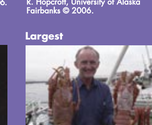
Darkest



CAML A community of marine life shrouded beneath ice 700 m thick and 200 km from open water surprised Census Antarctic scientists, who filmed scores of species including a jellyfish, possibly *Cosmetirella davisi*, swimming with tentacles raised.

AGAD, D. Raoch © 2006.

Largest



NaGISA Among the many new species discovered by Census participants during 2006, the 4-kg rock lobster that a Census explorer found off Madagascar may be the largest. Named *Palinurus barbarae*, the main body spans half a meter.

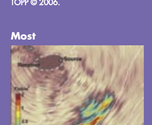
J. Groenevelt, Marine and Coastal Management, South Africa © 2006.

Oldest

CenSeam Census seamount researchers found a "Jurassic" shrimp, *Neoglyphea neocaledonica*, believed extinct for 50 million years, alive and well on an underwater peak in the Coral Sea.

B. Richer de Forges © 2006.

Most



GoMA Eight million herring swimming in a school the size of Manhattan off the New Jersey coast qualified as most abundant. Focused sound, like the beam from a lighthouse, scans ocean areas 10,000 times larger than previously possible. Instantaneous and continuous updates reveal the extension and shrinking, fragmentation and merging of fish schools.

N. Makris © 2006.

DISCOVERING DIVERSITY

Because species are the currency that measures the diversity of life, finding and naming a new one adds, while the extinction of an old one subtracts from the wealth of known biodiversity. Millennia of exploration and two centuries of naming species, combined with extinctions, might have diminished the chance of finding new ones. Instead, new technology, exploration of new regions, and new efficiencies of identifying and archiving are accelerating the discovery of species and expansion of known diversity.

More new than old

CeDAMar Discovering that wholly new species outnumber known ones exemplifies the acceleration of discovery. During three cruises of several months each, Census Antarctic scientists, trawling the depths of the remote Southern Ocean, found more new than already known species among the animals they brought on board.

Below: Southern Ocean isopods. *Acanthaspidia left*, and *Munnopsis* right. W. Broekeland © 2005.

Squat lobsters

CenSeam Scientists have found an abundance of squat lobsters inhabiting the seamount chains north of New Zealand. These creatures, when sitting on the ocean floor, often tuck their tails beneath them and assume a squatting position. Investigators have identified more than 611 species of Galatheoidea, including some new ones, in the Indo-Pacific Ocean alone.

Below: Diverse Galatheids and Chirostylids. R. Webber, Museum of New Zealand Te Papa Tongarewa © 2006, specimens not to scale.

Komoki in Antarctic waters

CeDAMar Komokiacea or 'komoki' dominate deep-sea foraminifera, protozoans with false feet used for locomotion and food collection. In the Weddell Sea, where ice crushed the ship of Antarctic explorer Shackleton in 1915, Census polar researchers found 59 komoki and komoki-like species, at least 42 unknown to science.

Below: A new species of komoki of the genus *Ipoa* found in the Weddell Sea. A. Gooday, National Oceanography Centre, Southampton, UK © 2006.

A squid that chews

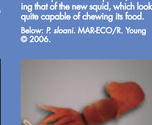
MAR-ECO Among the 80,000 organisms, encompassing 354 families, genera, and species that Census deep sea investigators collected from the Mid-Atlantic Ridge was the reference specimen or holotype for a new species of squid: *Promachoteuthis sloani*. Although collection easily damages the soft cephalopods, the hard beaks are unique to each species, including that of the new squid, which looks quite capable of chewing its food.

Below: *P. sloani*. MAR-ECO/R. Young © 2006.

Macro microbe

COMARGE The protozoan that Census explorers of the continental margins discovered in the Nazaare Canyon off Portugal differs from the usual protozoans seen swimming in a drop of water under a microscope. The single cell of this fragile new species of *Xenophyophore*, found at 4,300 m depth, is enclosed within a plate-like shell, 1 cm in diameter, composed of mineral grains.

Below: *Xenophyophore* in sediment. A. Gooday, National Oceanography Centre, Southampton, UK © 2006.



Researchers world wide

CoML Participants at a Scientific Steering Committee meeting in Reykjavik, Iceland. J. Ausubel © 2006.

TOPP Biologists download information from tags retrieved from seals. J. Bradley, www.bradleyphotographic.com © 2006.

CReefs Teams that discovered scores of new species on the French Frigate Shoals, Hawaii. NWHIMNM © 2006.

Doubling zooplankton

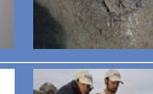
CMarZ Census zooplankton researchers discovered 3 new genera and 31 new species of copepods and mysids, small crustaceans, in Southeast Asian, Australian, and New Zealand waters. Analysis of collections from biodiversity hotspots, the deep sea, and other unexplored regions is on track to double the number of known zooplankton species.

Below: *Luciutia aurita*, one of many copepod species being studied by Census scientists. R. Hopcroft, University of Alaska Fairbanks © 2006.

Furry crabs

ChEss Near Easter Island, Census vent explorers discovered a crab so unusual it warranted a whole new family designation, Kiwaidae. Beyond adding a new family to the wealth of known biodiversity, its discovery added a new genus, *Kiwa*, named for the mythological Polynesian goddess of shellfish. Its furry or hairy appearance justified its species name *hirsuta*.

Below: *Kiwa hirsuta*, the Yeti crab. Ifremer/A. Fifis © 2006.



CHARTING DISTRIBUTION

New and extended techniques let scientists collect and tag creatures in order to follow their movements. Marine animals themselves are recruited as oceanographers, mapping their travels in the world's oceans. With their help, the Census is meeting the challenge of picturing the present and shifting distribution of global marine life.

Wider ranges

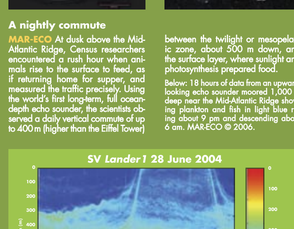
ArcOD/MAR-ECO When studying distribution, the surprise of finding a species in a new place is as exciting as the discovery of a new species. A species in a new place may indicate the species adapted, the environment changed, or the area was seriously under sampled. During 2006, counts rose to 31 species in the Arctic outside their known range, plus 60 species never before seen over the Mid-Atlantic Ridge between Iceland and the Azores.

Below: A new larvacean species found in the Canada Basin (left). R. Hopcroft, University of Alaska Fairbanks © 2006 and an unidentified Arctic deep sea sponge. B. Bluhm, I. MacDonald, NOAA © 2006.

A nightly commute

MAR-ECO At dusk above the Mid-Atlantic Ridge, Census researchers encountered a rush hour when animals rise to the surface to feed, as if returning home for supper, and measured the traffic precisely. Using the world's first long-term, full ocean-depth echo sounder, the scientists observed a daily vertical commute of up to 400 m (higher than the Eiffel Tower) between the twilight or mesopelagic zone, about 500 m down, and the surface layer, where sunlight and photosynthesis prepared food.

Below: 18 hours of data from an upward-looking echo sounder moored 1,000 m deep near the Mid-Atlantic Ridge showing plankton and fish in light blue rising about 9 pm and descending about 6 am. MAR-ECO © 2006.



Needles in haystacks

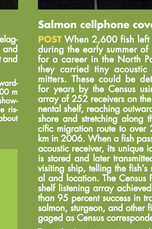
CeDAMar The span from schools of countless herring down to single animals of a species among thousands collected typifies the range of scale challenging Census' charting. The rich diversity of the isopod crustaceans includes common species and others rarely observed. In its exploration of Antarctic seas, the figurative haystack, Census researchers found many new species, especially isopod species, represented by only a single animal, the figurative needle, among thousands of specimens collected.

Below: Southern Ocean isopod, *Munnopsis*. W. Broekeland © 2005.

Salmon cellphone coverage extended

POST When 2,600 fish left rivers during the early summer of 2006 for a career in the North Pacific, they carried tiny acoustic transmitters. These could be detected for years by the Census using an array of 252 receivers on the continental shelf, reaching outward from shore and stretching along the Pacific migration route to some 2,000 km in 2006. When a fish passes an acoustic receiver, its unique identity is stored and later translated to a visiting ship, telling the fish's survival and location. The Census Pacific shelf listening array achieved more than 95 percent success in tracking salmon, sturgeon, and other fish engaged as Census correspondents.

Top right: Acoustic receivers ready to be deployed to the ocean bottom to track migrating fish. POST © 2006.
Right: Tagged salmon released into the Pacific Ocean. POST © 2006.



Dams and survival

POST Soon after salmon leave a river for the ocean, many perish. For decades people have wondered if salmon that have struggled to reach the river mouth through many dams might be less likely to survive in the open ocean than those that enjoyed youth in a free-flowing river. Initial counts suggest that survival of stocks leaving dammed rivers is comparable to those leaving rivers without dams.

Right: Salmon being tagged. POST © 2006.

Most complete registry

GoMA During 2006, experts in the Gulf of Maine released the first nearly comprehensive list of known species in this ecosystem, numbering 3,317, more than twice the number on prior lists. Researchers continuously refine and add to the registry, which includes marine life from microscopic phytoplankton up to right whales and from seasonal migrants to year-round residents.

Below: *Anarhichas lupus*, the Atlantic wolffish. P. Auster, P. Donaldson, National Undersea Research Center at the University of Connecticut © 2006.

ASSESSING ABUNDANCE

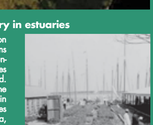
Although every living individual will never be counted, rational appraisal of hazards and effective management requires not only censuses but the reliable data the Census obtains. Such new technology as that employed to observe island-sized schools of herring plus novel mining of historical and data archives advanced the global network toward a reliable census by 2010.

Proportion of protected coral reefs

FMAP/CReefs Analysts in the Census network concerned with the future of marine animal populations compiled the first-ever global assessment of the extent, effectiveness, and omissions of coral reefs as Marine Protected Areas. Contributing to and using the Census' information system, they found that less than two percent of coral reefs worldwide are protected from extraction, poaching, and other major threats. They built their worldwide database of protected areas for 102 countries, including satellite imagery of reefs.

Degradation and recovery in estuaries

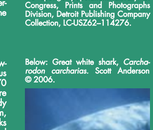
HMAP In archives such as taxes on salt to cure fish, Census historians reconstructed the changing abundance of marine life in 12 estuaries and coastal seas around the world. In archives from Roman times in the Adriatic Sea, the medieval era in Northern Europe, to Colonial times in North America and Australia, they confirmed the fears that exploitation and habitat destruction depleted 90 percent of important species. They also confirmed the elimination of 65 percent of seagrass and wetland habitat, a 10 to 1,000-fold degradation of water quality, and accelerated species invasions. More happily, they also found signs of transitions from degradation to recovery where conservation was implemented during the 20th century.



Above: A sponge yard along the docks in Nassau, Bahamas, c.1904, when harvesting largely eliminated the sponge population. Library of Congress, Prints and Photographs Division, Detroit Publishing Company Collection, LC-USZ62–114276.

Absent in space

MAR-ECO Absence is the lower limit of abundance. Census researchers discovered that 70 percent of the world's oceans are shark free. In an extensive study of the vast abyss below 3,000 m, deep-sea scientists found sharks were almost entirely absent and sought physiological and other explanations. Although many sharks live down to 1,500 m, they fail to colonize deeper, putting them more easily within reach of fisheries and thus endangered status.



Below: Great white shark, *Carcharodon carcharias*. Scott Anderson © 2006.

Assessing abundance demands efficiency

CMarZ The Census zooplankton team performed the first DNA barcoding of plankton on a ship underway, telescoping what formerly took years of work into just three weeks, an approach that may revolutionize pushing the boundaries of knowledge.

Below: Barcode (expanded horizontally) of the frigate tuna, *Auxis thazard*. FishBol © 2006.
Vials of copepods ready for sequencing. M.D. Allison, WHOI © 2006.

Scarce in time

MAR-ECO Although energetic exploration by the Census may uncover species long unseen, the appearance of a longtime absentee may be a clue to rising abundance. An expedition to the Mid-Atlantic Ridge, for example, captured 300 fish species. Several fishes captured had not been seen since a 1910 expedition, and others considered rare were found common. The change in abundance could reflect removal of predators or limited sampling in the past.

Above: A proposed new species of eel pout of the genus Lycodonus collected on the Mid-Atlantic Ridge. P.R. Møller © 2006.

Building and accessing the marine life database

OBIS During 2006 the linking of 143 databases multiplied the number of records in the Census' information system 2.5 times—from 4,000,000 in 2004 to more than 10,000,000. During 2006 the number of species encompassed and mapped rose from 40,000 to 75,000. The library of short DNA sequences, or barcodes for identifying marine animals, grew past 4,000, including 2,000 fish. Those in the Census database also clearly define the unknown ocean.

OBIS © 2006.

Prepared by J.T. Carlton & Staff, Census Office of Marine Biogeography, University of Rhode Island