High-seas Biodiversity and Genetic Resources: Science and Policy Questions

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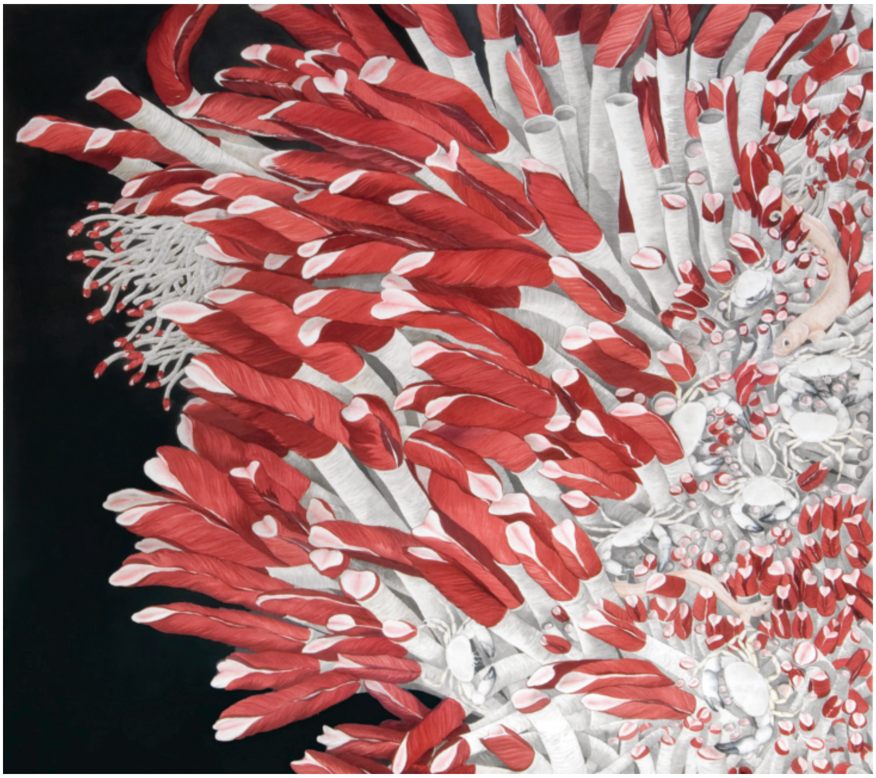
Global efforts to protect marine genetic resources and high-seas biodiversity peak in 2010.

This is a very eventful year for the conservation and study of high-seas biodiversity, with developments that put relevant policy and scientific directions at a significant crossroads. In February, the ocean division of the United Nations (UN) reconvened a special working group on marine genetic resources and biodiversity. The Convention on Biological Diversity (CBD) holds its 10th Conference of the Parties in October; it is expected to decide on high-seas conservation and ecological criteria, building on the work of recent CBD expert workshops and the Global Oceans Biodiversity Initiative. The context for deep-seas scientific research also changes in October with the culmination of the decadelong Census of Marine Life (COML), and marine scientists are eager to continue the momentum of discovery that the COML spawned. Moreover, by proclaiming 2010 the International Year of Biodiversity, the UN garners even greater attention for these high-seas policy and scientific efforts.



Deep-sea hydrothermal vents, discovered in 1977, support dense communities of tube worms and other previously unknown life forms. Art by Karen Jacobsen.

With these timely developments come important conservation, equity, and research questions: How do we protect deep-seas biodiversity against irresponsible exploitation in hard-to-monitor areas? How do we equitably govern the use of marine genetic resources while also fostering advanced scientific research? These are difficult

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Census of Marine Life in 2010

The 10-year international effort to assess the past, present, and future of marine biodiversity, the Census of Marine Life (COML), culminates this October with a ceremony in London's Museum of Natural History. Comprising 17 projects as diverse as the International Census of Marine Microbes and Tagging of Pacific Predators, the census has been the instigator of thousands of species discoveries, more than 3000 publications, and a worldwide network of more than 2000 scientists from 80 countries. The census has a number of publications coming out this year, including a coffee-table book on its findings for the general public (National Geographic), and a collection of reports from the census's 17 projects: *Life in the World Oceans: Discovery, Distribution and Abundance* (Wiley Blackwell).

COML Senior Scientists Ron O'Dor and Patricia Miloslavich have an extremely busy 2010, leading to the culmination of the census this October in London. New funding opportunities may extend some of the census's individual projects. Photographs: Courtesy of Ron O'Dor and Patricia Miloslavich.

"The census is a testament to a change in the way biologists are thinking about the oceans," says Ron O'Dor. He and Patricia Miloslavich, senior scientists with the COML, emphasize the census's great success in bringing scientists together and their hope for some form of continuation after 2010. Miloslavich points out that the extensive network of census-associated scientists is of great importance, because to understand the oceans "it is not possible to work in isolation." The census's cooperative approach ensured that researchers minimized duplication and maximized resources. O'Dor agrees, citing the census's Ocean Biogeographic Information System (OBIS) project, an online source of species baselines and other biological information: "Sharing the data in OBIS and other forums is the key."

The 10-year structured framework of the COML was guided by a central principle that helped develop working relationships. Reflecting the guiding ethic of the census's founding Alfred P. Sloan Foundation, O'Dor comments: "the 'known, unknown, and unknowable' has been the backbone of the census. We asked ourselves a decade ago about the known and unknown, and this guided us." Miloslavich explains that this principle was implemented through "KUU" (known, unknown, and unknowable) workshops, held from 2003 through 2007, which involved the census's National and Regional Implementation Committees. According to Miloslavich, these committees "brought to the census a local flavor from around the world." A collection of articles from these census committees will be published in 2010 in the journal *PLoS One*.

As the census concludes, O'Dor and Miloslavich reflect on its enduring legacy and the importance of building on its achievements. OBIS, for example, will continue under the auspices of the Intergovernmental Oceanographic Commission of UNESCO, but the future of most of the census projects is uncertain. "The census was at heart about both discoveries and baselines," O'Dor says. "We were amazed at what we found, and we laid down new baselines that allow us to monitor change." According to the census, conservation measures enhance the resilience of the oceans, and with dramatic change expected for oceans habitats, O'Dor says. "The census should be done every 10 years." What really excited her most as a biologist, Miloslavich says, "is that the age of discovery is not over and won't be for a long time.… Ten years ago we had a sense of our needing to know more of areas like the deep seas or groups such as bacteria. Now that we put it all in a big picture, we know better where to concentrate our efforts."

issues, and they intersect with the grand question that scientists continue to ask: How do we fathom the dazzling biodiversity of the multihabitat, remote frontier that is the deep sea?

Myriad habitats and species

The deep seas comprise a great variety of habitats that foster a wide range of biodiversity and functional relationships. Jeff Ardron, director of the High Seas Program for the Marine Conservation Biology Institute, says some very good recent studies distinguish certain deep-sea habitats, but with 99 percent of the deep oceans unexplored, "it is very hard to characterize all habitats; it is safe to say that there must be several hundred that would be readily identifiable."

Species found in the deep seas often have no near resemblances to terrestrial or coastal species. Cindy Van Dover, a deep-sea biologist and director of the Duke University Marine Laboratory, says species diversity in the deep-sea soft sediment plains rivals that of tropical rainforests. She expresses wonder at the expanding knowledge of deep-sea marine biology: “The deep ocean is so unexplored that each year brings some profound or curious new discovery or observation, from tongue fish that skitter across ponds of molten sulfur in the deep Pacific to slender tube worms that colonize natural asphalt eruptions in the Gulf of Mexico, looking like weeds beside a highway.”

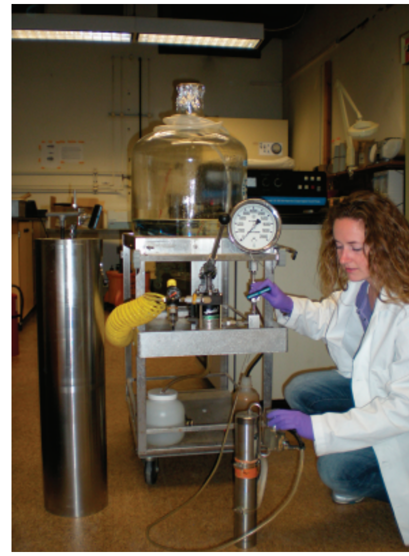
Van Dover’s research focuses on animals that live in extreme deep-sea environments, especially hot springs. Species in these habitats, she says, “can teach us about the extremes to which life on Earth can adapt…and challenge us to understand how these adaptations can be applied to societal needs.” One such example is *Crysomallon squamiferum*, the scaly-foot snail, which Van Dover and her team discovered in 2001 as part of an exploratory dive to the Kairei hot springs on the Central Indian Ridge in the Indian Ocean. Van Dover describes the scaly-foot snail as “unlike any other modern or even fossil snail.” This snail’s foot is shingled with scales, and its shell and scales are fortified with iron sulfide, a characteristic previously unheard of in the animal kingdom, Van Dover says. Since its discovery, the scaly-foot snail has been the focus of biomimicry investigations looking for human, vehicular, and structural armor applications.

The shell and scales of the scaly-foot gastropod Crysomallon squamiferum are fortified with iron sulfide, a characteristic previously unheard of in the animal kingdom. Photograph: Cindy Van Dover.

Microbial Milky Way

Discoveries of astonishing deep-sea vertebrates and invertebrates might offer practical uses, and the significant expansion in the understanding of marine microorganisms has revealed the great number of species with the potential for research and commercial use. Woods Hole microbiologist Mitchell Sogin leads the International Census of Marine Microbes (ICoMM), one of the COML’s projects. Not only did the ICoMM deliver new knowledge about microbial diversity in the oceans, Sogin says, but it also provided a new model for conducting science on a global scale with collaboration from laboratories from around the world. Of the three groups of marine microbes (Archaea, Protista, and Bacteria), the ICoMM concentrated on bacteria, but its findings were of far-reaching import for all marine biodiversity. The study found that marine microbial species are at least 10 times—possibly 100 times—more diverse than initially thought.

Douglas Bartlett, a microbiologist at Scripps Institution of Oceanography who focuses on deep-sea microbes, describes the deep-sea environment as “a far cry” from its 19th-century depiction as an azootic place, too dark and under too much pressure to support life. “One has to realize that the environmental microbial sciences today provide a microscopic view of microbial constellations, including those within deep-sea habitats, that is a lot like astronomy,” Bartlett says. “In fact it looks like a micro–Milky Way.” Whether the deep sea has more biodiversity than the terrestrial Earth is unresolved. “Based on the estimates of bacterial and archaeal abundance at depth [around 10^{29} cells for the ocean water column, even more in sediments] and the diversity of deep-oceanic microbes that have been assessed thus far,” he reflects, “it is indeed possible that the greatest amount and diversity of life on Earth could be that existing in darkness a kilometer or more from the surface.”



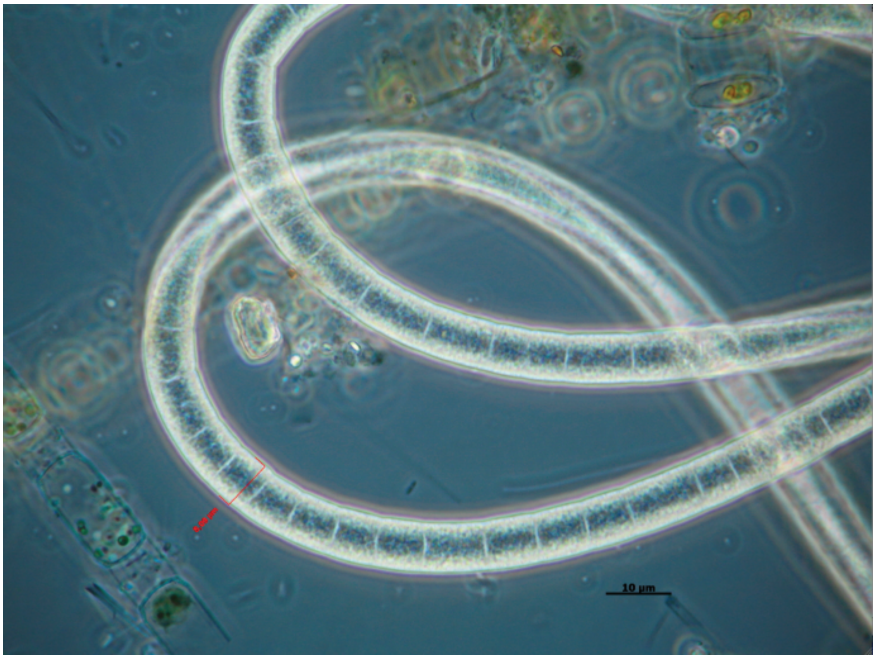
Great advances have been necessary for understanding marine microbial life, such as techniques for preserving and culturing deep-sea organisms adapted to high pressure. Photograph: Emily Eloe.

Both Sogin and Bartlett highlight the technological and other advances needed to understand marine microbial life. For example, new techniques have been developed for preserving and culturing deep-sea organisms adapted to high pressure: “A parameter,” Bartlett says, “that has been extremely influential in the evolution and distribution of life in deep-seas environments.” Emily Eloe, a graduate student at the University of California, San Diego, who studies deep-sea microorganisms with Bartlett, explains that investigations in the deep-sea Puerto Rico Trench rely on new genetic and culturing technologies. “Previously only a few types of media—mostly a high-nutrient medium—were used to culture microbes from the cold, deep sea,” she says. “Our lab has built large-volume pressure vessels to accommodate high-throughput techniques to test more medium types at once.” As a result, Eloe and her group found “high diversity at the bacterial phylum level, as well as certain groups which appear to have a depth-specific distribution" in the Puerto Rico Trench, where the pressure is up to twice as high as in the nearby abyssal plain.

Genetic technologies are certainly key to understanding microbial diversity, and many biologists note Sogin's innovative use of massively parallel pyrosequencing. In recent years, scientists have dramatically increased this technology's sequencing capacity, and today, Sogin says, "massively parallel pyrosequencing can produce between 400,000 and 1.2 million sequence reads of each 400 to 600 base-pair length in a single run of the instrument." He explains how the process works with species estimates: "The sequences of genes like ribosomal RNA [rRNA] coding regions only serve as proxies for the presence of a microbe in a complex microbial community. We can only estimate how much change in an rRNA gene correlates with 'species level' differences for microorganisms." As scientists learn more about rRNA sequences and genome variation, Sogin adds, the rRNA differences ascribed to different kinds of microbes will very likely prove an underestimate of diversity. The similarity of rRNA sequences among microbes with very large genetic differences implies horizontal gene flow between distantly related organisms, challenging the very notion of bacterial "species."

High-seas genetic resources and the vagaries of international law

While biological investigations accelerated in the last decade, policy discussions intensified for marine biodiversity in waters beyond national jurisdiction—those ocean areas beyond a nation's 200-mile exclusive economic zone or continental shelf extension. In 2007, the regularly convened UN Open-ended Informal Consultative Process on Oceans and the Law of the Sea held a discussion on marine genetic resources that was marked by unresolved disagreements. The UN General Assembly also set up a separate working group, formally called "the Ad hoc Open-ended Informal Working Group to study issues relating to the conservation and sustainable use of marine biological diversity beyond areas of national jurisdiction." Meeting for the third time in February 2010, this working group has emerged as the lead forum for high-seas marine genetic resources issues.



Giant sulfur bacteria were found in anoxic sediments in the eastern South Pacific Ocean in 2004. Photograph: Carola Espinoza, Universidad de Concepcion, Chile.

The dispute over marine genetic resources is fundamentally a matter of international law under the UN Convention on the Law of the Sea (UNCLOS). However, the CBD also plays an important advisory role: It conducted a 2009 workshop on ecologically and biologically significant areas and has coinstigated the Global Oceans Biodiversity Initiative, which is facilitated by the International Union for Conservation of Nature (IUCN) and supported by the German government.

Nations differ as to which part of the UNCLOS text is determinative. Australian oceans law expert Robin Warner explains that there are basically two arguments in the debate. On one side, she says, there is a bloc of states that believes marine genetic resources are the common heritage of mankind and should be administered under a regime similar to Part XI and the Part XI implementing agreement, which pertain to deep seabed minerals and which established the International Seabed Authority. On the other side are the countries, most prominently the United States, that believe marine genetic resources should be administered according to UNCLOS's Part VII, which stipulates the freedoms granted for the high seas, such as the right to fish on the high seas (Article 116). Part VII also contains significant articles on conserving high-seas living resources. "The real division between the two bodies of opinion," Warner says, "seems to lie in their approach to access and benefit sharing of the resources rather than any disagreement as to the conservation of the biodiversity associated with the resources."

This debate hinges on the interpretation of the UNCLOS's vision. Deep-seas legal expert Kristina Gjerde, the high-seas policy adviser for the IUCN, says that marine genetic resources were not in the purview of the UNCLOS negotiators. "Hydrothermal vents were discovered in 1977," she says, "and it was only because geologists were looking for them." Gjerde

This deep-sea shrimp from the Coral Sea, discovered in 2005, belongs to a group previously believed to have gone extinct 50 million years ago. The "Jurassic shrimp," as this exciting discovery came to be known, led to the designation of a new genus describing these archaic shrimp. Photograph: B. Richer de Forges, IRD.

says that biological resource questions generated little or no attention within the contemporaneous UNCLOS negotiations that culminated in 1982. Warner agrees, saying some version of the common-heritage principle should apply to deep-seas genetic resources, because they have many potential "medical, pharmaceutical, industrial, and agricultural applications," and that a new understanding for marine genetic resources under UNCLOS would be beneficial.

David Balton, the US Department of State's deputy assistant secretary for oceans and fisheries, is another longtime oceans law expert, and he has been part of the effort to get the United States to finally ratify UNCLOS, a goal the State Department lists as a priority for this congressional term. He offers a different historical perspective: "Even in the 1970s, people were aware that marine genetic resources existed. The negotiators of UNCLOS chose to create an access and benefit-sharing regime for minerals on and under the seafloor beyond national jurisdiction, but they chose not to create such a regime for marine genetic resources. In developing the 1994 implementing agreement, the negotiators again chose not to extend the Part XI regime to marine genetic resources." Balton says that Part VII deals with all parts of the ocean beyond national jurisdiction, including the seafloor, and he joins Warner in pointing to UNCLOS's crosscutting provisions that oblige nations to conserve high-seas living resources.

These varying interpretations underscore different worries. Balton expresses concern that regulating access and benefit sharing of marine genetic resources in areas beyond national jurisdiction would inhibit scientific research. Warner and Gjerde, on the other hand, stress how difficult it is for developing countries to conduct and benefit from genetic resource discovery. "It is about equity," says Gjerde. "Equity is not only for nonliving resources but, according to the modern concept of sustainable development, for all living resources, too. In many respects developing countries feel they are losing out, as they don't currently have the capacity for bioprospecting or making intellectual property claims, like patents, for discoveries."

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In the interim, Balton, Gjerde, and Wagner agree that significant steps can be taken. For example, Gjerde highlights the importance of high-seas marine protected areas and suggests that in the short term, it would be beneficial to have a UN General Assembly resolution, on the basis of CBD criteria and guidance, that calls on states to work cooperatively on ecologically and biologically significant areas in the high seas. Warner describes how combining environmental impact assessments and strategic environmental assessments with marine protected areas can minimize adverse impacts on the fragile habitats and species surrounding hydrothermal vents and other relevant hot spots of marine genetic resources.

Learning more about which deep-seas resources are being used is another key interim measure. Marjo Vierros, a marine ecologist by training, focuses on this at the UN University Institute of Advanced Studies. "It is important that the current policy discussions are based on as much information as possible," she says. Her office began documenting the use of Antarctic genetic resources in 2004 and deep-sea genetic resources in 2005. This work entails extensive searches of diverse sources and databases, and Vierros encounters many complexities. For example, a patent application might list that a sample was collected from a hydrothermal vent in the midocean ridge, but this could be either within or beyond national jurisdiction, she explains. "Exact coordinates would provide us with certainty."

One verified patent Vierros mentions is for an enzyme isolated from a marine strain of the fungus *Aspergillus,* collected from sediments 5000 meters deep in the Central Indian basin and now used in laundry detergents. Although the ongoing legal debate pertains to species found at or below the sea bottom, there are also property claims for species from the high-seas water column. For example, there are more than 500 krill-related patents from the global krill supply, with 300 from Southern Ocean krill, which have a critical place in that food web. The myriad uses for krill raise concerns that overharvesting will alter the Southern Ocean ecosystem. Similarly, recent interest in patents from Sargasso Sea seaweed could also lead to potential overharvesting of this ecosystem component, one on which endemic marine species depend and that is found nowhere else.

This unknown cnidarian from the deep Arctic Canada basin was attached to a second species of cnidarian when it was grabbed with the manipulator arm of a remotely operated underwater vehicle, or ROV. Photograph: Bluhm/Iken.

Future intersects

Krill, Sargasso Sea seaweed, and many other deep-sea species offer significant opportunities for research and highlight policy questions about safeguarding these species and their habitats. There is also real concern, say Bartlett and Sogin, over the impact that elevated carbon dioxide in the atmosphere and consequent ocean acidification will have on microbial communities, which are the base of the marine food web and account for at least 50 percent—maybe as much as 90 percent—of all oceanic carbon fixation. Finding the right balance will not be easy, but there are interim measures available, drawing attention to the issues and assuring their importance is appreciated.

"In the deep sea," Van Dover reflects, "there live creatures of extraordinary beauty, exquisitely adapted to extraordinary environments. We may choose to threaten their habitats and existence to solve problems we have created or to gain economic or strategic advantage, but we should make this choice based on an understanding and knowledge of what we will lose as well as what we will gain. Unlike on land, where there may be means of restoring damaged habitats, when we compromise habitats in the deep sea, we don't know the consequences, and there may be no easy remediation."

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