Title: With Half the Planet up for Grabs, A Call for Deep-Ocean Stewardship

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1-Sentence Summary. With a mounting imperative to advance stewardship strategies that consider the special features of the deep ocean and ensure that this biome serves future generations, we must promote long-term, deep-ocean sustainability through precaution, knowledge creation, and governance development.

Abstract – Not provided for Policy Forum

Main Text

Few pause to consider the deep ocean – the largest biome on Earth covering more than half the planet (and representing much more by volume). Yet the deep ocean sequesters one third of the atmospheric CO_2, recycles critical nutrients, and holds millions of yet-to-be-described species. It is home to the largest daily migrations on the planet — kilometer-long living ladders of fishes, and invertebrates whose travels connect surface productivity to the deep– and stores mind-boggling quantities of untapped energy resources, precious metals, and rare elements. A domain of many mysteries, the deep ocean beneath 200 m remains largely ignored and unexplored.

Human population rise and consumer demand has created growing food, energy, and raw materials shortages on land and in the nearshore environment, leading industry to look toward deep-ocean resources. With engineering advances that greatly improve access to the deep sea, this immense, remote biome now faces unprecedented challenges to its integrity and its ability to provide services upon which we depend (*1*). Furthermore, indirect effects of human activity on land are affecting the deep ocean, including climate change impacts. With this mounting imperative to advance stewardship strategies that consider the special features of the deep ocean and ensure that this biome serves future generations, we must promote long-term, deep-ocean sustainability through precaution, knowledge creation, and governance development. What is needed is a strategic and holistic environmental planning effort that balances future mineral, energy and living marine resource extraction with a sustainable, productive, and healthy marine environment. This goes beyond what can be done through single-sector management, and should include regional-scale planning that takes into consideration cumulative impacts to biodiversity and ecosystem services, accompanied by a research agenda for actionable science. As interest in the deep ocean expands, new funding sources for deep ocean research are imperative.

Deep ocean opportunities and services abound. The deep ocean can be as varied as terrestrial landscapes with unique features and ecosystems (2) that provide critical regulating services for the planet (*3*) and give rise to an array of living, energy, and mineral resources (*4*). Tens of thousands of seamounts covered with cobalt-rich crusts provide habitat for dense aggregations of long-lived fishes and corals, many with lifespans of 100 years or more (*5*). Expansive abyssal plain ecosystems are an essential piston in the biological carbon pump that draws CO_2 out of the atmosphere and buries it in the seabed (*6*). Where the abyssal plain is covered with metal-rich nodules that grow a few millimeters in a millennium, exploration leases are enabling industry to evaluate the potential to exploit nodule-bound manganese, cobalt, copper, nickel, and rare-earth elements increasingly needed for modern technology (*4*). Hot springs on submarine volcanic mountains support communities of microbes, worms, mollusks, and other organisms exquisitely adapted to chemicals in the fluids rising from the ocean crust (*7*). These hot springs deposit ores containing copper, zinc, and, sometimes, silver and gold—treasures buried on national and international seabeds. Mud-covered continental margins accumulate organic matter that, over geological time, is transformed into energy reserves of oil, gas and methane and creates islands of seeping chemicals that support deep-sea life in profusion. These margins also host spectacular deep-water reefs that are critical nursery grounds for fishes and other organisms (*8*). Elsewhere on the margins, fossil phosphate deposits hold the promise of future sources of fertilizers.

In all, this complex domain supports biodiversity rivaling that of tropical rainforests. These deep dwellers—including many microbes, protozoa and small multicellular animals—represent a living library of genetic resources, providing the raw material that will allow life in the ocean to evolve and adapt to changing climate conditions, and may one day yield biomaterials, industrial agents or pharmaceuticals critical to human well-being (*9*).

With use comes impact from fishing, energy development, mineral mining (Fig. 1), and bioprospecting – but also stress from waste disposal, contaminants and CO_2-related changes in temperature, oxygen, pH, and productivity (*4*). The global trawling footprint is estimated to be 20 million km^2 (*10*), equal to more than the land mass of the United States and Canada. One-fifth (4.4 million km^2) of the continental slope has been trawled at least once and often multiple times (*10*). Gear innovations and advances in electronic and information technology have increased capability to trawl in canyons, over seamounts, and across rugged slopes—habitats that once offered refugia to fishes and other organisms.

Oil and gas development since the 1970s has led to almost 2,000 deep-water exploration wells (*11*). Despite setbacks caused by the *Deepwater Horizon* oil spill, the number of wells deeper than 300 meters in the Gulf of Mexico is expected to almost double by the end of 2015 (*12*). While the footprint of any individual drilling operation may be small, *Deepwater Horizon* has demonstrated the large areal impact of an oil disaster at such depths (*13*). Deep-sea mining, long viewed as a boom of the future, is upon us now. Already an area more than twice the size of Germany (883,000 km^2) has been leased in the Pacific's Clarion Clipperton Zone by 19 nations for manganese mining exploration at depths of 4,000 meters and more. Mining companies are exploring hydrothermal vents for polymetallic sulfides and seamounts for cobalt crusts, abyssal sediments for rare earth elements, and productive margin sediments for phosphates.

The deep ocean has also served as an intentional dumping ground. More than 50,000 metric tons of radioactive waste dumped in the Northeast Atlantic from 1949-1970 is a legacy of nuclear testing (*14*). Toxic terrestrial mine tailings are discarded in the deep ocean; Norway, for example, has disposed of millions of tons of such waste in 22 of its deep submarine fjords (*16*). Looking forward, the deep ocean may provide a receptacle to other types of dumping, including sequestered carbon dioxide as one possible way to combat climate change (*15*). The seabed is also the unintended final resting place for a surprising array of anthropogenic debris and pollutants (*4*).

User conflict is growing. As we identify new ways to exploit the resources of the deep ocean, conflicts are expanding in both national and international waters. Already, fishing and mineral or energy extraction industries clash over exploitation, as do those engaged in traditional uses on the one hand and industrial development on the other (*17*). Conflict also arises between the prospect of exploitation of known resources and preservation of the unknown potential of the deep ocean. Wholesale removal of the seafloor surface associated with mining of phosphates, massive sulfides, cobalt crusts or manganese nodules, for example, will remove organisms whose genetic or enzymatic attributes may one day benefit humankind.

The deep ocean is not just about extraction and waste disposal. It is a place from which to draw inspiration through the knowledge of myriad creatures of the deep, the potential to discover new species with novel adaptations, the possibility of advancing science and medicine, and more—

values that may conflict with industrial exploitation. These existing and potential conflicts call for a governance approach that enables decision-makers to make explicit tradeoffs among the functions and services the deep sea provides.

Governance is fragmented. The inhabitants of deep-ocean ecosystems ignore geo-political boundaries. The water column and the seabed below 200 meters extend from national (near-shore) to international jurisdictions (offshore); both are typically managed on a sector-by-sector basis, if at all.

The United Nations Convention on the Law of the Sea (UNCLOS) provides an umbrella framework for most aspects of deep-ocean management, but the agreements and institutions that build from this ‘constitution for the oceans’ exist in siloes. In marine areas beyond national jurisdiction, regional fishery management organizations (RFMOs) are typically narrowly focused on regulating commercial fisheries harvest but are disconnected from other sector-based activities, such as mineral resource extraction, which is overseen at the international level by the International Seabed Authority (ISA). While the ISA is charged with addressing environmental impacts caused by mining, it lacks the jurisdiction to regulate non-mineral activities. As currently constructed, a protected fisheries nursery habitat under one management system could be a target for mining exploitation under another. Management of other activities (for example shipping, dumping, laying submarine cables, and military activities) that affect the deep ocean are equally siloed, and in some instances, such as exploitation of marine genetic resources, specific agreements and management institutions are substantially lacking (*18*).

The United States federal system of ocean management provides another example. Deep-ocean federal fisheries are managed by RFMOs and the National Marine Fisheries Service in accordance with the Magnuson Stevens Fishery Conservation and Management Act. Regulation of minerals, oil, and gas resource exploitation falls under the purview of the Bureau of Ocean Energy Management and the Bureau of Safety and Environmental Enforcement in accordance with the Outer Continental Shelf Lands Act. While both laws create some interagency linkages in the form of consultation requirements, neither law sets up a decision-making system that allows for specific tradeoffs among potentially conflicting uses and minimization of cumulative impacts. That said, the U.S. is advancing an integrated system of ocean stewardship through its National Ocean Policy (NOP)—an umbrella approach that calls upon federal agencies, states, and tribes to work collaboratively at the regional level to establish integrated marine plans to guide exploitation and conservation of ocean resources. Although much of the U.S. EEZ contains deep-ocean areas, the NOP has little focus on deep ecosystems and resources, and few legal requirements are specifically tailored to address environmental management of the U.S. deep ocean.

A Path Forward

Given the still largely unknown nature of the deep ocean, we envision stewardship that necessarily embraces a precautionary approach to avoid or minimize human impact, while allowing use of deep-ocean resources to support human well-being and protection of the important but undervalued ecological functions and ecosystem services. We envision a stewardship system that reduces risk through collaborative governance and advances deep-ocean knowledge.

1. **Use precaution and minimize impact.**

In a realm of overwhelming information constraints, action without sufficient precaution could lead to the irreversible loss of as-yet-undiscovered resources and critical ecosystem services. What is known gives rise to concerns about potential long-term impacts of human activities. Distinct deep-ocean ecosystems persist and operate at different spatiotemporal scales, spanning months and years in the water column, years and decades at hydrothermal vents, thousands of years for seamount corals, and millions of years in abyssal nodule fields. Thus recovery from human disturbance will depend on the ecosystem.

The lack of knowledge on deep-sea ecosystem structure, function, and dynamics should constrain managers to protect known at-risk resources, avoid impact to unknown resources, and establish strong requirements to avoid or minimize harm. Typically, mitigation includes avoiding or minimizing harm, and, where harm is unavoidable, restoring key ecosystem characteristics following an extractive or other human activity. Restoration of many deep-ocean habitats will be very expensive, challenging, and, in some instances (e.g., cobalt crust, manganese nodule beds) impossible or impractical (*19*). These factors call for a different approach: in lieu of restoration in the classic sense, deep-ocean managers should focus on preservation and expansion of knowledge as restoration tools. Such an approach has been used before: in the *Exxon Valdez* oil spill, natural resource damage restoration included the development of a research fund (20) (an approach that has also been called for in the *Deepwater Horizon* oil spill (*21*)), and U.S. law allows preservation as a form of wetlands mitigation in some circumstances (*22*).

2. **Advance deep-ocean knowledge.**

Developing the knowledge needed to manage the deep ocean requires a leap from desktop study and shallow-water analogy to strategic deep-water scientific research. We lack quantitative models to estimate the value of deep-ocean ecosystem services. And for most deep-sea ecosystems, we lack the information necessary to inform spatial planning and determine mitigation and restoration strategies (e.g., species ranges, their natural variability and dynamics, dispersal distance, demographics, genetic connectivity, or the many factors that affect community diversity, vulnerability to impacts, and resilience following disturbance).

This lack of knowledge translates into management challenges, as demonstrated by the *Deepwater Horizon* oil disaster. With a legal mandate to restore the injured natural resources, US managers (and researchers) have faced the impossible task of piecing together an ecosystem that was never adequately studied, along with how millions of gallons of introduced oil and dispersant disrupted it. One way to develop the requisite knowledge base is to establish funding mechanisms as part of mitigation, leasing, licensing, and liability systems. Such sources could support the baseline research and monitoring needed to inform management institutions charged with regulating exploitation of deep-ocean resources.

3. **Move toward collaborative governance.**

Overcoming fragmented governance requires new approaches to collaboration. Marine spatial planning efforts around the world, including the U.S. National Ocean Policy, provide templates for national and international action. These existing approaches recognize the need for interdisciplinary, transboundary, and cross-sectorial management to ensure that cumulative impacts are minimized and explicit tradeoffs are made. In the deep ocean, such collaborative governance must span national and international frameworks and result in action by those institutions responsible for fisheries, shipping, oil and gas, and deep-ocean mining, among others. To enable such collaboration (i) information-sharing amongst governance bodies, industry, and researchers will likely need to be improved, (ii) formal procedures mandating cooperation and integrated deep-sea research and planning should be established, including the participation of civil society, and (iii) collectively agreed-upon goals, objectives, and indicators of progress/success will must be formulated, monitored, and reported upon.

Moving forward, the growing recognition that the deep ocean is an important repository of fossil and living resources should be balanced with protection of the deep sea and its ecological functions. We call for a progressive environmental management approach that moves us from a frontier mentality of exploitation and single-sector management to a cross-sector, precautionary, ecosystem-based approach that takes into account the heterogeneity, critical functions, sensitivity, knowledge gaps, and governance limitations in the deep sea.

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This compilation depicts ongoing and potential resource extraction activities of humans in the deep sea and habitats and animals that could be affected by them.

HABITATS (not to scale), clockwise from upper left: MANGANESE NODULE FIELDS (> 4000 meters deep): Manganese Nodules Mining Collector; Sea Cucumber (Holothuroidea); Jellyfish, (Voragonema pedunculata); Deep-Sea Anglerfish (Melanocetus johnsoni); Tripod Fish (Bathypterois grallator). Manganese nodules form extremely slowly – adding a centimeter over several million years. PHOSPHATE MINING as proposed on the margin off Namibia: Granule Airlift System to recover phosphates for fertilizer; Hake Fish (Merluccius merluccius); Bearded Goby (Sufflogobius bibarbatus); Jellyfish (Chrysaora africana) - a food chain of interdependent species. METHANE SEEPS: Subsea Spar Well with tubular risers for drilling and water injection, used in oil drilling at depths of 2,000-10,000 feet; Tube Worms (Lamellibrachia luymesi) can live more than 250 years; Mussels (Bathymodiolus childressi); Brine Seep; Yeti Crab (Kiwa hirsuta); Deep Sea Crab (Chaceon quinquedens). SEA MOUNT FISHING: Deep Ocean Bottom Trawl Net (100 meters wide) - with trawl doors, each weighing up to 9,000 pounds; Blackbelly Rosefish (Helicolenus dactylopterus); Orange Roughy (Hoplostethus atlanticus) lives up to 149 years; Blobfish (Psychrolutes marcidus); Squat Lobster (Munida quadrishpina; Cold-water Coral (Lophelia pertusa); Bubblegum Corals (Paragorgia arborea); Feather Star (Florometra serratissima). HYDROTHERMAL VENTS: Seafloor Production Tool (SPT) for mining of copper, zinc and gold. This roughly 25 foot high tool can be used as deep as 6,000 meters; Black Smoker Vents; crab (Shinkaia crosnieri); White Bacterial Mats (Beggiatoa alba); Hydrothermal Vent Mussel (Bathymodiolus thermophilus); Giant Tube Worms (Riftia pachyptila). These deep-ocean ecosystems host a "living library" of genetic resources, including many new and yet-to-be discovered species.