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A Call for Deep-Ocean Stewardship

The precautionary approach and collaborative governance must balance deep-ocean use and protection.

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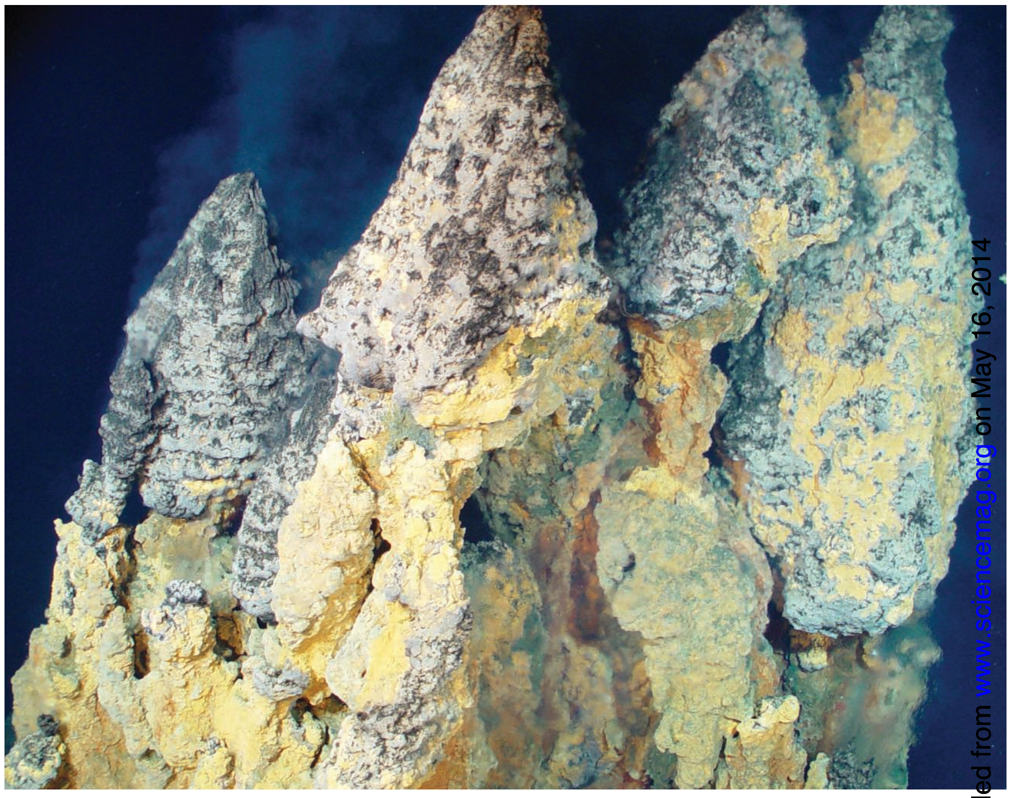
Covering more than half the planet, the deep ocean sequesters atmospheric CO_2 and recycles major nutrients; is predicted to hold millions of yet-to-be-described species; and stores mind-boggling quantities of untapped energy resources, precious metals, and minerals (*1*). It is an immense, remote biome, critical to the health of the planet and human well-being. The deep ocean (defined here as below a typical continental shelf break, >200 m) faces mounting challenges as technological advances—including robotics, imaging, and structural engineering—greatly improve access. We recommend a move from a frontier mentality of exploitation and single-sector management to a precautionary system that balances use of living marine resources, energy, and minerals from the deep ocean with maintenance of a productive and healthy marine environment, while improving knowledge and collaboration.

We have an opportunity to make smart decisions now about the future of the deep ocean ahead of expanding and emerging uses—decisions that weigh benefits of use against both direct costs of extraction and external costs that include damage to sensitive and unknown ecosystems and their services that would be difficult to repair or replace.



Minerals from the deep. Active "smoker" chimneys precipitating iron, copper, and zinc sulfides from 230°C fluid in the Mariana Arc region, Western Pacific Ocean.

Expanding Use, Fragmented Governance

The deep ocean already experiences impacts from activities such as fishing; oil and gas development; waste disposal; and land-based pollution, including greenhouse gases (*2*). On the horizon is industrial-scale mining combined with impacts from CO_2 emissions, which will alter temperature, pH, O_2, and food supply to the deep (*3*). Together, these will inflict a spectrum of impacts that, if not managed wisely, may irreversibly damage essential ecosystem functions, processes, and services (see the figure).

Industrial fishing in the deep ocean is moving inexorably deeper; the mean depth of fishing activity has increased by 350 m since 1950 (*4*) and is largely unsustainable, removing long-lived, low-productivity species that cannot recover on reasonable time scales (*5*). Bottom trawling in effect "clear-cuts" hundred-year-old fishes and thousand-year-old corals on seamounts and continental margins. One-fifth of the continental slope (4.4 million km^2), which largely occurs below 200 m, has been trawled at least once and often multiple times (*6*). Only a few countries benefit briefly from the yield, but habitat loss is widespread and largely permanent in human time scales (*2*). In response to the recognized devastation caused by trawling in the deep ocean, the European Parliament recently took measures to restrict such trawling in the northeast Atlantic, building on calls by the United Nations for urgent action. Many believe that the actions do not go far enough and advocate a complete ban.

Since the 1970s, the oil and gas industry has drilled almost 2000 deep-ocean exploration wells (*7*). The probability of accidents increases markedly with water depth, about 8.5% with every ~30 m of platform depth (*8*). Although the footprint of any individual drilling operation may be small, the Deepwater Horizon spill has demonstrated a worst-case-scenario oil disaster at great depths (*9*). This event highlighted the paucity of baseline data for deep-ocean ecosystems in the Gulf of Mexico and elsewhere. Such data are fundamental for evaluating impacts to, protecting, and restoring lost resources.

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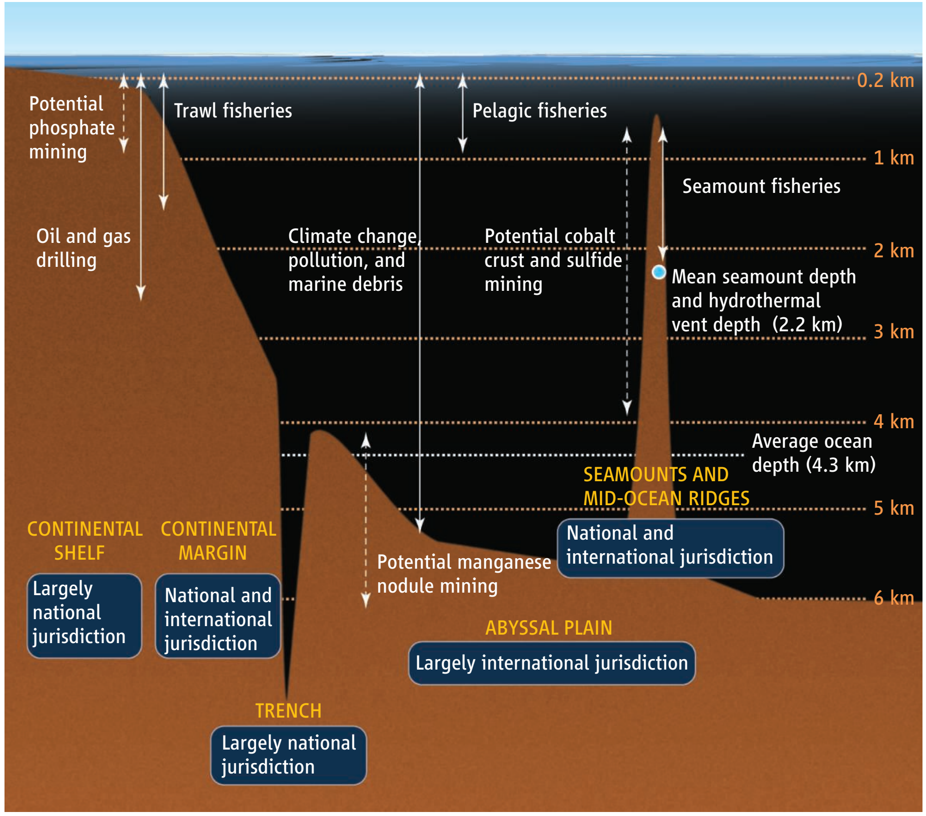
Deep-ocean mining is an emerging industry with national and international regulations under development now. Already, the International Seabed Authority has entered into eleven 15-year contracts with nations leasing an area more than twice the size of Germany (883,000 km²) in the abyssal central Pacific (>3500 m) for polymetallic nodule exploration. Mining companies and nations also have leases in national and international areas to explore hydrothermal vents for deposits of massive polymetallic sulfides, seamounts for cobalt crusts, and margin sediments for phosphates. (See the photo and the figure.)

The deep ocean has served as an intentional dumping ground for radioactive waste, sewage, toxic chemicals, and terrestrial mine tailings (*2*). It is now being considered as a long-term storage site for CO_2 to combat climate change (*10*). The deep ocean is also the unintended final resting place for an array of land-based anthropogenic debris and pollutants (*2*).

Expanding use brings cumulative impacts and conflicts that will likely grow as we identify new ways to exploit the deep ocean. Already, fishing and mineral or energy extraction industries clash over exploitation (*11*). Deep-water phosphate deposits off Namibia, New Zealand, and Mexico are being targeted for use as fertilizer. These phosphates occur in waters that support productive coastal fisheries important to local economies and communities. Such overlapping uses and multisector activities generate cumulative impacts that are difficult to monitor and quantify in the deep ocean (*2*). Conflict also arises between those wishing to exploit resources and those seeking to preserve species and habitats.

Governance in the deep ocean is fragmented. The water column and the seabed below 200 m are interconnected, extending across national and international jurisdictions (see the figure), but are managed on a single-sector basis, if at all. The 1982 United Nations Convention on the Law of the Sea (UNCLOS) is an umbrella framework for international ocean management. Multilateral regional fishery management organizations regulate commercial fisheries harvest; the International Maritime Organization manages shipping; and the International Seabed Authority regulates mining of the international seabed. Management of other activities (dumping, laying submarine cables, and military activities) that affect the deep ocean is similarly a single-sector approach. In some arenas, like marine genetic resource management, agreements and institutions are substantially lacking (*12*). These single-sector approaches, necessary for managing specific activities, are not sufficient to ensure balanced resource use and sustainability. An example of the challenge is playing out now on the Chatham Rise in New Zealand: the site proposed for deep-ocean phosphate mining overlaps with an existing "benthic protection area" that prohibits bottom trawling under New Zealand fisheries requirements.



Existing and potential uses and impacts in the deep ocean.

A Path Forward

In the face of uncertainty, a growing number of international treaties and other instruments adopt the precautionary approach (*13*), which as explained in the 1992 United Nations Rio Declaration on Environment and Development, recognizes that "[w]here there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." The deep ocean is challenged by threats of irreversible damage where there are slow rates of substrate formation (manganese nodules may precipitate a few mm per million years) and slow growth and maturation of the deep biota. The task for deep-ocean management in national and international areas is to achieve appropriate precaution while enabling use of living and nonliving resources. Here, we propose three directions to advance deep-ocean stewardship: (i) protection and mitigation, (ii) research, and (iii) collaborative governance.

(i) Protection and mitigation. We recognize the great expense and near impossibility of restoring many deep-ocean ecosystems (*14*). These facts alone demand a precautionary approach that includes appropriate protection of areas that are representative of targeted habitat as well as ecologically, biologically, and scientifically important. An expert-driven planning process has been used to delineate a network of appropriate sites for protection in the manganese nodule-covered Clarion Clipperton Fracture Zone of the Central Pacific Ocean (*15*), an approach that could be adopted for other regions.

Representative protected areas that have the same geomorphic, physical, chemical, and biological characteristics as existing and planned exploitation areas should be established as effective refuges and as a source of brood stock for species likely to be affected. The International Seabed Authority has established as part of its management plan for the Central Pacific Ocean, nine "Areas of Particular Environmental Interest" that have many of these features; however, the designations are so far not permanent and apply only to mining. In addition, established control areas are required for baseline mea-

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surements and as a reference for monitoring impact and mitigation. To be effective, protected areas must be multisector in application to avoid damage by one sector when protected by another.

Typically, mitigation includes avoiding or minimizing harm and, where harm is unavoidable, restoring key ecosystem services. With known sensitive resources, avoiding and minimizing harm can be achieved through buffer zones or heightened siting standards. For example, U.S. oil and gas guidance calls upon those operating below 300 m to establish 76- to 610-m buffer zones around deep-sea corals and chemosynthetic communities, depending on the activity. New research on plume effects and other impacts will be required to understand buffer-zone requirements for deep-sea mining activities.

When harm is unavoidable and the ecosystem will be damaged, compensatory restoration can help address loss. However, the impracticality of restoration in the deep ocean in most instances calls for a different approach. In lieu of restoration in the classic sense (e.g., fixing injured resources or establishing new sites with the same features), deep-ocean managers should focus on protection and expansion of knowledge as restoration tools. Yet-to-be-discovered species, habitats and functions must be safeguarded while scientific understanding required for ecosystem-based management and mitigation techniques (*14*) are developed. "Research as restoration" is an approach with precedence; the *Exxon Valdez* oil spill restoration plan included the development of a research fund (*16*). A similar approach has been called for in the Deepwater Horizon oil spill (*17*). Although these examples arise from catastrophic spills, the approach is relevant to mitigation for planned injury, as occurs with permitted activities like fishing and mining. In addition, U.S. law allows preservation (protected areas) as a form of compensatory mitigation when other approaches are not feasible (*18*).

(ii) Research. For most deep-sea ecosystems, we lack basic information on species composition and distribution ranges, their natural variability and dynamics, dispersal distance, demographics, connectivity, and the many factors that affect community diversity. Modeling is required to estimate vulnerability to impacts and resilience after disturbance, as is valuation of deep-ocean ecosystem services.

One way to develop the requisite knowledge base is to establish funding mechanisms as part of leasing, licensing, mitigation, and liability systems under national and international frameworks (*19*). For example, U.S. law requires electricity revenues from the Bonneville dam to fund a fish and wildlife program, including scientific research to mitigate impacts. Beyond information generation, such funding should support a global deep-ocean data repository, such as the Ocean Biogeographic Information System (OBIS).

The International Seabed Authority has entered into eleven 15-year contracts with nations leasing an area more than twice the size of Germany … in the abyssal central Pacific … for polymetallic nodule exploration.

(iii) Collaborative governance. Overcoming fragmented governance requires improved collaboration. Marine spatial planning efforts recognize the need for interdisciplinary, transboundary, and multisector management to ensure that cumulative effects are minimized and explicit trade-offs made. Among these trade-offs are the environmental, social, and economic trade-offs between deep-ocean and terrestrial resource extraction. For example, deep-ocean minerals can occur at higher concentrations, are closer to the sediment surface, and will likely require less permanent mining infrastructure for extraction than terrestrial minerals. Weighing against deep-ocean mining is the lack of knowledge about mining impacts and ecosystem resilience, the likelihood of slow to no recovery for many habitat types, the lack of ability to monitor and restore damaged systems, and the potential disturbance to seafloor and water-column life far beyond mining sites.

Marine spatial planning approaches provide a template for deep-ocean management and will require formal procedures for improved information-sharing among governance institutions, industry, civil society, and researchers; collectively agreed-upon goals and objectives; careful monitoring and reporting; improved compliance and enforcement; and transparent, participatory processes. For international waters and seabed, a new implementing agreement to UNCLOS for the conservation and sustainable use of marine biodiversity beyond national jurisdiction, as has been proposed by many nations to the United Nations, could provide a platform for international collaboration, coordinated management, and precaution.

Given our substantial knowledge gaps, any future exploitation of deep-ocean resources must be balanced with lasting protection of habitats, biodiversity, and services.

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