



## POLICY FORUM

### OCEAN GOVERNANCE

# *An ecosystem-based deep-ocean strategy*

Monitoring and assessment must underpin development of a new international agreement

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Increasing exploration and industrial exploitation of the vast and fragile deep-ocean environment for a wide range of resources (e.g., oil, gas, fisheries, new molecules, and soon, minerals) raises global concerns about potential ecologi-

cal impacts (1–3). Multiple impacts on deep-sea ecosystems (>200 m below sea level; ~65% of the Earth's surface is covered by deep ocean) caused by human activities may act synergistically and span extensive areas. Cumulative impacts could eventually cause regime shifts and alter deep-ocean life-support services, such as the biological pump or nutrient recycling (2, 4, 5). Although international law and national legislation largely ignore the deep sea's critical role in

the functioning and buffering of planetary systems, there are promising developments in support of deep-sea protection at the United Nations and the International Seabed Authority (ISA). We propose a strategy that builds from existing infrastructures to address research and monitoring needs to inform governments and regulators.

Growing demands for ocean space and seabed resources have generated a need for international laws and policies (6) to enable

A submersible explores the deep seafloor and collects data for assessing the impacts on vulnerable deep-sea biodiversity.



holistic management of deep-ocean use. These new policies are needed because (i) a large portion of deep-sea environments falls in areas beyond national jurisdiction (ABNJs) and (ii) regulatory bodies for activities in ABNJs, such as the ISA and Regional Fisheries Management Organizations (RFMOs), are typically sector based, and this limits potential cooperation across sectors. The UN Convention on the Law of the Sea (UNCLOS) recognizes the right of all states to access marine living resources in ABNJs, together with the obligation to cooperate with other states to protect and

preserve the marine environment. These environmental obligations have been neither well specified nor implemented.

The UN is developing a new international agreement that could potentially overcome these challenges by enabling comprehensive ecosystem-based management of ABNJs. By the end of 2017, a preparatory committee (PrepCom) will deliver recommendations to the UN General Assembly for a new, legally binding instrument under UNCLOS on the conservation and sustainable use of marine biodiversity in ABNJs. On the basis of those recommendations, in 2018, the UN General Assembly will decide whether to negotiate a final treaty. The specific topics addressed to date are (i) marine genetic resources, including questions on sharing of benefits; (ii) area-based management tools, including marine protected areas (MPAs); (iii) environmental impact assessments; and (iv) capacity-building and the transfer of marine technology.

In parallel with the UN effort, the ISA is developing rules to govern exploitation of minerals in the deep seabed ABNJs. UNCLOS requires the ISA to administer seabed-mining activities on behalf of all humankind. Deep-sea ecosystems targeted by the mining industry require baseline assessments, monitoring strategies, and environmental impacts assessments to evaluate natural spatial and temporal variability and to develop mitigation and restoration strategies (7). The ISA's 2012 Strategic Environmental Management Plan (SEMP) in the equatorial eastern Pacific Ocean established a representative network of areas closed to mining covering 1.44 million km<sup>2</sup> of seabed (8). The ISA is not competent to regulate other activities, such as deep-sea bottom fishing on seamounts, which may impinge upon areas protected from mining. The new UN treaty offers an opportunity to incorporate provisions for comprehensive planning, coordinated management, and long-term monitoring to complement ISA regulations and plans (9). This will require improved knowledge and holistic monitoring.

#### CHALLENGES AND OPPORTUNITIES

Ecosystem-based management of activities affecting seafloor and water-column biodiversity will require knowledge of a wide variety of ecological and biological variables (e.g., biodiversity, life cycles, functional variables, trophic interactions, and organic-matter cycling) supported by abiotic measurements and detailed habitat mapping. The Global Ocean Observing System has started to iden-

tify “essential ocean variables” for the deep sea but the list is yet to be finalized. The paucity of ecological data challenges our ability to identify priority and/or representative areas for MPAs. The ISA's SEMF, for the Pacific, designated nine (no-mining) Areas of Particular Environmental Interest (APEI) almost exclusively on environmental proxies, including bathymetry and models of particulate-organic carbon flux (3, 10). Ecosystem-based indicators were limited or unavailable. Although this APEI network provides a measure of precaution, systematic and comprehensive ecosystem-based management demands more comprehensive knowledge and specific conservation measures.

Accordingly, as part of the new international agreement, and to complement the ISA initiatives, governments at the UN should commit to developing holistic, global Deep-Sea Ecosystem Monitoring Networks (DEMNs), primarily focused on organisms and ecosystems, with physical and chemical metrics as key, explanatory variables. A sustainable management strategy for the deep ocean should establish science-based conservation goals, develop a global framework for defining baseline conditions, and establish monitoring requirements. Such a strategy must include objectives and definitions of key variables and indicators. It must consider the spatiotemporal frequency of biological data sampling necessary to document the ecological heterogeneity and status of the seabed and water column at depth. The

***“A global deep-ocean monitoring strategy would... protect and restore deep-sea ecosystems...”***

strategy should allow for revisions based on increasing understanding.

To stimulate development of our proposed DEMN, the new UN agreement should incorporate (i) the principle of ecosystem-based management as a priority objective, and (ii) mechanisms to operationalize precautionary management of activities in ABNJs, such as environmental status goals, thresholds, and indicators. A dedicated international agency, e.g., “International Deep-Ocean Organization,” under the umbrella of the UN, could promote transnational funding mechanisms and provide resources and direction to ad-

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dress gaps in research, monitoring, data management, and transparency.

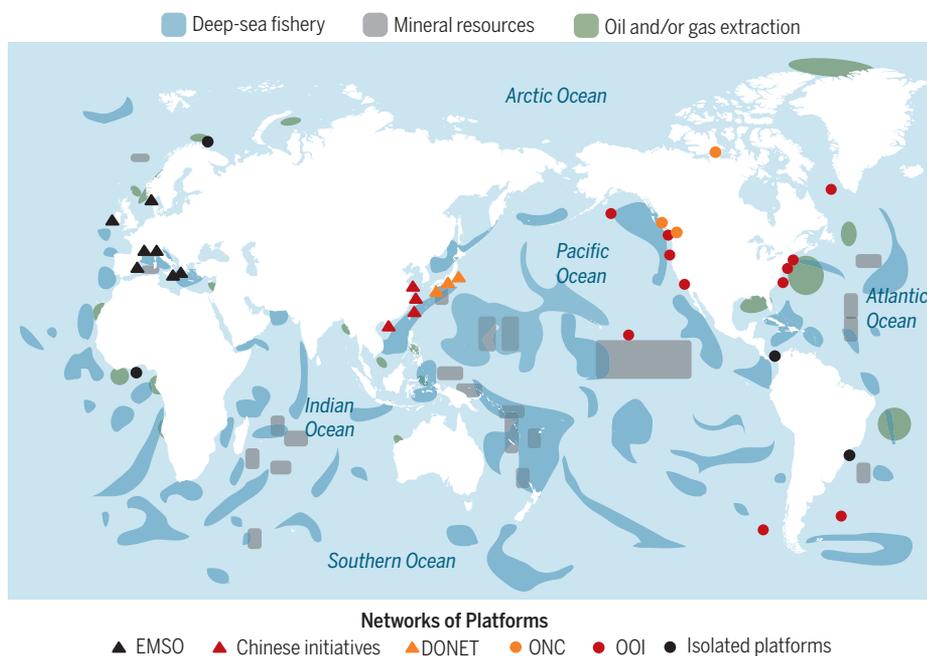
Alternatively, such a function could be granted to the UN Intergovernmental Oceanographic Commission (IOC), although its funding and capacity would need to be enhanced. Priority actions for such an agency should include (i) acquiring knowledge necessary for deep-sea management; (ii) integrating inputs from research institutions, academia, industries, and nongovernmental organizations; (iii) coordinating research resources and technologies across nations to address basin-scale and long-term scientific gaps; (iv) making data available to inform policy and resolve critical

must be integrated with mobile robotic platforms moving between nodes, to facilitate ecological monitoring at larger spatial scales.

Pelagic gliders, seafloor crawlers, instrumented buoys, and moorings could complement benthic networks of platforms to support comprehensive monitoring that connects seabed habitats with the overlying water column. By coupling imaging with active detection assets (e.g., tracking animals carrying acoustic tags and environmental data loggers), scientists could integrate passive and active sampling methods, introducing “animal-mediated intelligence” (12) (i.e., inferences on animal decisions based on perceived eco-fields). Acoustic and satellite

## Deep-sea observatories and areas of exploration and/or impacts

Video-cabled observatories are putative initial focal points for a deep-sea monitoring network expansion. See supplementary materials for details on source data.



needs; and (v) facilitating conversion of scientific knowledge into “good practices” for optimal governance of the deep sea.

A global deep-ocean monitoring strategy would expand our capacity to protect and restore deep-sea ecosystems and their resources. For instance, seabed ecology has benefitted from an increase in permanent deep-ocean monitoring stations (11), including cabled observatories [e.g., North-East Pacific Time-series Undersea Networked Experiments; Porcupine Abyssal Plain Sustained Observatory; and Ocean Networks Canada (ONC)] (see the map). Whereas these support real-time time-series studies, spatial resolution is limited to areas in proximity to cable-system nodes. Cabled observatories

technologies already monitor large-scale movements of key pelagic megafauna (13). Some of these organisms spend substantial time in ocean depths and could be prioritized for tagging studies. Molecular analyses, including barcoding and metagenomic investigations, can be applied at large spatial scales, expanding our ability to identify species, assemblages, their functions, and connectivity. Implementation of artificial intelligence in imaging (animal recognition and tracking) and data treatment (data banking and multivariate statistics) will facilitate operational autonomy in monitoring and delivering real-time information and support rapid decisions.

Deep-sea ecological science is limited less

by the capabilities of current ocean technologies than by their high costs (14). Support for a DEMN would benefit from, and likely require, sustainability incentives for relevant industries to pool resources and invest in subsea infrastructure and technologies enabling acquisition of biological data. Requirements for benefit sharing of profits from deep-sea mining in ABNJs could provide additional funds. Based on the costs and investments of Group of Seven (G7) countries in existing infrastructure, such as Canada (ONC), USA [Ocean Observatories Initiative (OOI)], and Japan [Dense Ocean-floor Network System for Earthquakes and Tsunamis (DONET)], as well as in Europe [European Multidisciplinary Seafloor and water-column Observatory (EMSO)], we estimate a cost of \$2 billion to \$3 billion for implementation and deployment of 20 strategically placed monitoring networks, with maintenance costs between \$0.2 billion to \$0.3 billion per year.

No current funding mechanism can deliver such resources, which will likely decrease in cost as technologies advance and use expands. Nonetheless, international organizations (e.g., UN, ISA, RFMOs) regulating activities in the oceans and industries operating therein need this research now. Long-lasting collaborative agreements should align international key players and industrial partners. We urge the next UN PrepCom in March 2017 to consider these proposals, which could fit well within the potential scope of the new international agreement now under discussion at the UN.

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### SUPPLEMENTARY MATERIALS

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