

1 A Decade to Study Deep-Sea Life

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4 *The UN Decade of Ocean Science for Sustainable Development presents an exceptional*
5 *opportunity to effect positive change in ocean use. We outline what is required of the deep-*
6 *sea research community to achieve these ambitious objectives.*

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8 The health of the global ocean, on which society depends, is in decline. The importance of
9 sustainable use to ocean health has long been recognized¹, yet the United Nations First
10 World Ocean Assessment² from 2017 highlighted increasing ocean pressures from
11 accelerated expansion of human activities, including climate change. These pressures affect
12 all ocean regions, from the coast to the deep sea³. In response to this concern, and to align
13 with several international policy commitments, the United Nations General Assembly
14 proclaimed 2021-2030 the Decade of Ocean Science for Sustainable Development⁴.

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16 The roadmap for this Ocean Decade recognizes the deep sea as a frontier of science and
17 discovery, and calls for research to advance understanding of deep-sea ecosystems, their
18 functions, vulnerabilities, and services to society. Published in March 2020, the draft
19 implementation plan for the Ocean Decade guides the design and implementation of
20 'Actions' that underpin the desired move from "the ocean we have" to "the ocean we want"
21 (Fig. 1). The draft plan calls on the scientific community to develop Actions, at programme,
22 project, activity or contribution levels, to help deliver on four key objectives: 1. increase
23 capacity to generate, understand, manage, and use ocean knowledge; 2. identify and
24 generate required ocean data, information and knowledge; 3. build comprehensive
25 understanding of the ocean and its governance systems; and 4. increase the use of ocean
26 knowledge.

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28 The deep-sea biology community has responded to this call through working groups of the
29 Deep-Ocean Stewardship Initiative (DOSI) and the Scientific Committee on Oceanic
30 Research. In keeping with the Ocean Decade's focus on fair and equitable partnerships,
31 these groups include experts from developed and developing nations, representing diverse
32 ethnic backgrounds, different genders and career stages. Together, these groups have
33 considered the research needs associated with each of the four objectives in a deep-sea
34 biology context. Here, members of both working groups present recommendations under
35 each objective to inform the development of deep-sea focused Ocean Decade Actions.

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39 **Figure 1: Steps towards a sustainable deep ocean.** The UN's Ocean Decade aims to
40 understand the ocean we have, and drive progress to the ocean we want, via four
41 objectives. We have assessed the Ocean Decade's objectives through a lens of deep-sea
42 biology, and provide recommendations to support the development of Actions to achieve
43 these objectives.

44 *Objective 1: Capacity development*

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47 There is unequal capacity to conduct deep-ocean science among nations, with countries
48 with developing economies facing substantial barriers to participating in deep-sea research,
49 including access to technological capability and infrastructure, and to specific expertise.
50 Thus, although more than 70% of countries' Exclusive Economic Zones (EEZs) contain
51 deep-sea environments, most deep-sea research is conducted by only a small subset of
52 economically developed nations. Consequently, the least-studied parts of the deep sea are
53 within the EEZs of least economically developed countries and large ocean states (also
54 known as small island developing states). Availability of samples, data, and overall

55 knowledge of deep-sea ecosystems reflect these biases. Even where such nations can
56 participate, barriers to publishing in international journals often result in country-specific
57 publications only.

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59 Deep-sea focused Ocean Decade Actions must therefore strive to expand capacity
60 development by coordinating efforts across deep-sea research projects and regions to
61 provide sea-going opportunities for researchers from nations that have limited access to
62 large-scale infrastructures. All Actions should commit to co-developing and co-producing
63 transregional research at an early stage of design, partnering with local collaborators. The
64 planned research should value and build upon local / indigenous knowledge systems. This
65 approach will bring different perspectives and approaches to deep-sea research⁵, and
66 encourage a new generation of deep-sea scientists and educators by highlighting diverse
67 role models and opportunities. All Actions should facilitate open access to marine scientific
68 research outputs, marine technologies, and ocean knowledge, using best practices. These
69 should follow both the principles of being findable, accessible, interoperable, and reusable
70 (FAIR) and the principles of collective benefit, authority to control, responsibility and ethics
71 (CARE). Existing and planned UN-supported initiatives, such as the Ocean Biodiversity
72 Information System (OBIS), and the International Oceanographic Data and Information
73 Exchange should be employed. All Actions should commit to sharing specimens, including
74 whole animals, tissue, barcoding and environmental DNA samples, and invest in the
75 deposition of specimens in established and regionally relevant institutions that have
76 recognised charters to support permanent storage and care of archived specimens. We
77 recommend open access publication of research and data where possible.

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80 *Objective 2: Generate ocean data*

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82 Physical and biogeochemical observing programmes in the deep ocean have expanded
83 recently at local, regional and global scales. However, sustained biological observing
84 programmes have lagged behind, and only a handful of long-term study sites are in
85 operation⁶. Spatial bias occurs in biological ocean observations, with under-sampling of
86 equatorial and polar regions, and of the southern hemisphere more generally⁷. Globally,
87 sampling effort decreases with depth⁸. Although recent technological advances allow every
88 part of the deep ocean to be accessed, the capacity to deploy assets remains restricted
89 worldwide because of the high cost of suitable vessels and limited available infrastructure.

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91 A coordinated international effort is needed to expand deep-sea biological observations and
92 sampling in all ocean basins, specifically focusing on underexplored regions⁹. A blueprint for
93 a global-scale field programme using standardized methods, stratified by latitude,
94 biogeographic region and depth, among other key variables, has recently been prepared¹⁰
95 that addresses this issue. We recommend that Ocean Decade field-survey Actions follow
96 this blueprint to support completion of a global sampling 'jigsaw puzzle', designed to deliver
97 comparable scientific knowledge in all ocean basins. The blueprint also highlights the need
98 to identify biogeographically representative sites to initiate a globally comprehensive site
99 network for sustained observations.

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101 Expanding both spatial and temporal biological observations in the deep ocean will require
102 small and low-cost technologies to enable broader participation^{11,12}. Ocean Decade Actions
103 should build on existing efforts within our deep-sea research community to develop and
104 apply such technologies under a standardized framework.

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106 *Objective 3: Build ocean understanding*

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108 Despite increased research efforts in recent years, fundamental biological, ecological and
109 taxonomic information for much of the deep ocean is still urgently needed to improve the
110 predictions, forecasting and modelling that inform decision-making, policy, management and
111 innovation. Accurate prediction of how biodiversity will respond to climate change and other
112 anthropogenic pressures requires data on existing species, their biotic and abiotic tolerances
113 and interactions, in addition to better characterization of climate stressors at deep-sea
114 habitat-representative spatial and temporal scales. Effective ocean management and
115 sustainable use also critically depend on understanding deep-sea connectivity – linkages
116 among deep-sea ecosystems, communities, species and populations. A clearer
117 understanding of the role of the deep ocean in the provision of ecosystem services at
118 regional and global scales is also needed.

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120 Ocean Decade Actions must expand knowledge of offshore and deep-sea ecosystems and
121 associated anthropogenic impacts. Mapping the biological components of the deep sea,
122 describing what we have, where and how it lives is essential to achieving this objective. We
123 recommend Actions look to map ecosystem services delivered by the deep seas, and flows
124 of benefits to society. Evaluation of current baselines and human impacts across temporal
125 and spatial scales, following standardized methodologies and a dynamic stratified design is
126 needed. Through targeted sampling and experimentation, Actions should identify the role
127 and functioning of deep-sea biology, including those systems essential to ocean and human
128 health. The acquired information can then be used to map and quantify human impacts in
129 the deep sea and assess the feasibility of future restoration actions¹³. Collectively, this
130 knowledge will facilitate improved modelling and predictive capacity to deliver relevant and
131 timely societal services that can inform sustainable ocean management. These results can
132 feed into UN processes, as well as regional and national management bodies.

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134 *Objective 4: Increase use of ocean knowledge*

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136 Decision-making processes to ensure sustainable use of the marine environment require
137 synthesis of multiple streams of knowledge to reach evidence-based choices. Although
138 researchers have developed decision-support tools that have been applied to marine spatial
139 planning (reviewed in ¹⁴), few have been applied specifically to the deep sea¹⁵.

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141 Ocean Decade Actions should strive to inform ecosystem-based management to support
142 global, regional and local decision-making in the deep ocean. Working with the UN, and
143 relevant regional and national bodies, Actions should further develop and trial decision-
144 support tools and scenario-based systems for informed decision-making and adaptive
145 management at local to global scales. Actions should foster the development of effective
146 ‘knowledge to end-user’ pathways, building on already successful community initiatives, for
147 example the DOSI.

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149 *A ten-year research programme*

150 The Ocean Decade begins on 1 January 2021. Our recommendations provide a resource for
151 deep-sea biologists seeking to engage with the Ocean Decade through developing their own
152 Actions. However, they also provide the basis for the development of a deep-sea focused
153 programme-level Action designed to coordinate and monitor deep-sea research effort. Such
154 a programme could build on previous global decadal efforts, most recently the Census of
155 Marine Life (CoML) (2001-2010). The CoML brought together more than 2700 researchers
156 from around the world to evaluate the diversity, distribution, and abundance of life in the
157 global ocean. Of the 17 major projects under the CoML, five specifically focussed on deep-

158 sea ecosystems, and these provide key reference points. A new programme, designed
159 around the Ocean Decade objectives, would be more likely to generate the level of
160 knowledge advance needed to inform and support high-level policy processes, including the
161 Sustainable Development Goals and Aichi 2030 Targets, than individual project-level Actions
162 could achieve in isolation. We argue that a ten-year programme to enact our
163 recommendations is essential if we are to move to a more sustainable future for our deep
164 ocean. This Ocean Decade is the time to act, and we must all seize the opportunity.

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