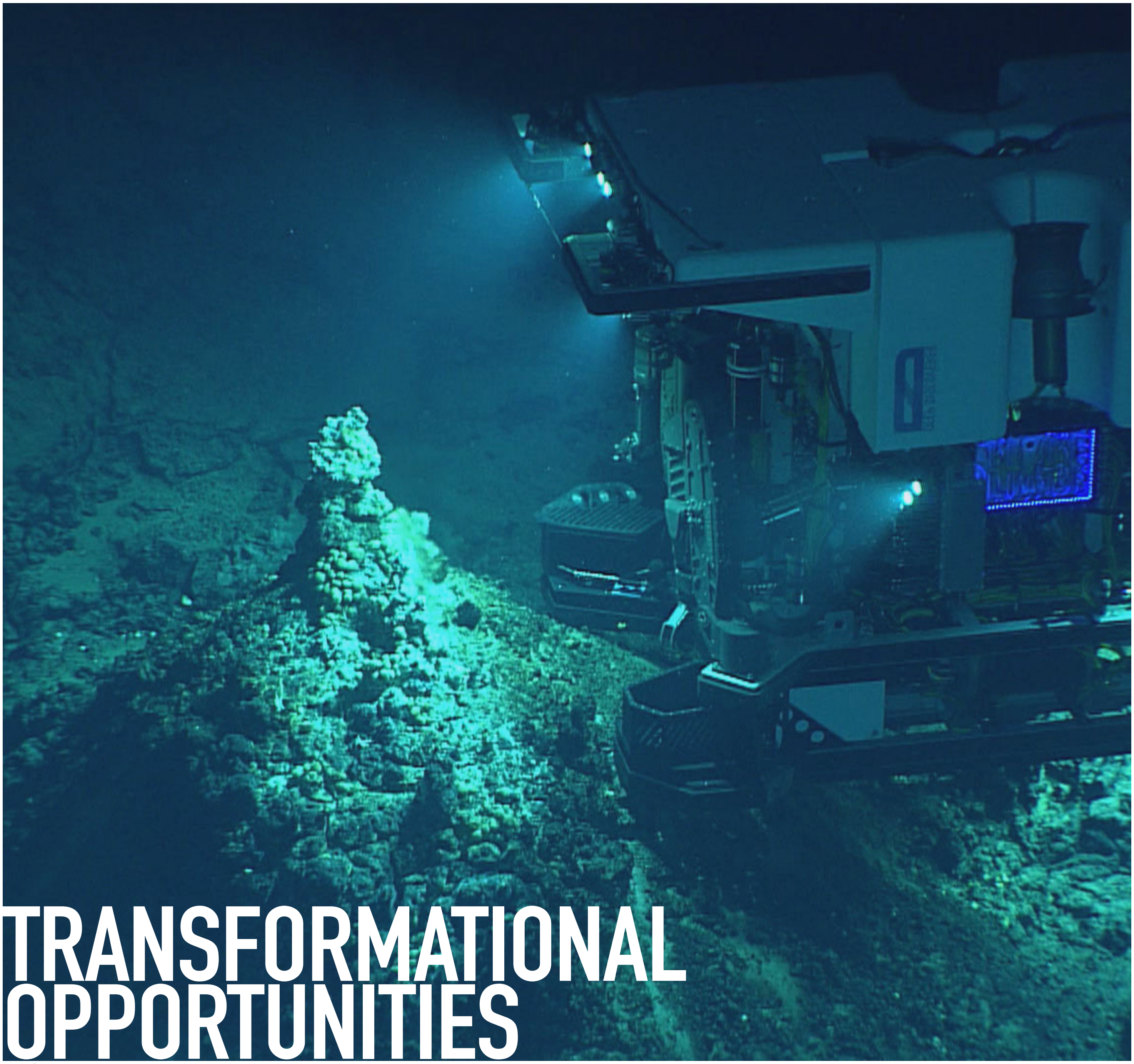

TRANSFORMATIONAL OPPORTUNITIES FOR PEOPLE OCEAN PLANET

MINERAL & GENETIC RESOURCES

Blue Climate Initiative

Blue Climate Initiative

This publication was commissioned by the Blue Climate Initiative (BCI), which accelerates ocean-related strategies, collaborating across a multidisciplinary global community towards a restored and healthy climate; an understood and protected ocean; and resilient, thriving and equitable communities. In 2020 the BCI initiated a holistic process to identify transformational opportunities at the intersection of people, ocean and planet, engaging over sixty world-class scientists and academics. These contributors compiled recommendations across six thematic areas: Health & Well-Being, Food & Nutrition, Marine Energy & Transportation, Mineral & Genetic Resources, Biodiversity & Nature-Based Solutions, and Sustainable Tourism. This publication is part of that series. The BCI is deeply grateful to its authors for their insights and collaboration.

A compendium synthesizing messages across the six Transformational Opportunities papers is available: Fries, L., Everett, J., and Davies, N. (eds.) 2021. Transformational Opportunities for People, Ocean, and Planet. French Polynesia: Blue Climate Initiative, Tetiaroa Society. https://doi.org/10.5281/zenodo.4540323.

For more information about the Blue Climate Initiative, please visit blueclimateinitiative.org or contact info@blueclimateinitiative.org.

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Mineral and Genetic Resources Transformational Opportunities

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Executive Summary

For at least 3.7 billion years, life has existed in the ocean resulting in rich biological and genetic diversity that underpins the functioning and resilience of a diverse range of marine ecosystems. Rapid technological advances have opened the door to exploration of the ocean. At a genetic level, they have informed taxonomic efforts, provided insight into the history of life on Earth, and led to a range of commercial benefits including through biotechnology applications such as the development of novel pharmaceuticals. Similarly, these advances have revealed metals and minerals formed in the ocean's remote depths over millennia to millions of years, primarily in polymetallic nodules on abyssal plains, ferromanganese cobalt-rich crusts on seamounts, and polymetallic sulphides around mid-ocean ridges and back-arc basins. While interest in extracting these minerals has grown in recent years, commercial mining of the deep seabed has not yet begun. Concerns exist about the ecological damage from industrial-scale mining disturbances, especially related to the loss of biodiversity and therefore of genetic resources. There are also further challenges related to the ethics, management, governance, and distributions of benefits for these nascent extractive industries, especially in an ocean increasingly impacted by climate change. Both mineral and genetic resources are of relevance to combating climate change, and the simultaneous urgency of addressing stark equity and inclusivity issues associated with their discovery, possible exploitation, and stewardship.

Within this context, our Blue Climate Initiative (BCI) Working Group proposes the following set of Transformational Opportunities:

1. **Fair Ocean**: Establish integrated marine research and education infrastructure based on promoting equity, inclusivity and diversity:
   a. International deep-sea station and ocean-observing infrastructure;
   b. Research Fleet for the World;
   c. AquaNet: Accessible and low-cost broadband across the ocean;
   d. Institute for the Fair Advancement of Ocean Research.
2. **Ocean Census 2030**: Continue the Census of Marine Life to get organismal and genomic data on all marine species including microorganisms.

3. **Ocean Tricorder**: Develop a tricorder that can assess marine life in real-time, including at a genetic level to lessen dependence on the infrastructure, equipment and other resources associated with sampling, transporting and analysing samples.

4. **Integrated Model of Ocean Life (IMOL)**: Build models of ocean biodiversity function to understand the role of species and networks, especially in carbon cycling and climate-change mitigation.

5. **SeaVal**: Holistically quantify the value of intact marine ecosystems, especially those most likely to be affected by the extraction of mineral and genetic resources, and the services they provide, including carbon cycling and climate-change mitigation.

6. **Deep Finance**: Incorporate ambitious sustainability criteria into mainstream finance instruments associated with the use of the ocean's mineral and genetic resources.

7. **SeaComm**: Develop a communication strategy and associated movie or series of programmes focused on the deep ocean and associated anthropogenic issues. This will raise awareness, leading to increased stewardship.

8. **Climate for International Marine Biodiversity (CLIMB)**: Push for the uptake of climate considerations of all activities into the negotiations on areas beyond national jurisdiction.

Scope

This Working Group focuses on the importance of the rich and, to a large extent, unknown biodiversity in a rapidly changing ocean, while mainstreaming principles of equity and inclusivity into the responsible discovery and stewardship of the ocean's mineral and genetic resources.

Introduction

In many parts of the ocean, genetic resources overlap with, and often are even attached to, mineral resources, with industrial-scale extraction of mineral resources therefore posing a substantial but poorly quantified risk to biodiversity[1,2]. Value propositions unavoidably become based on limited perceptions of the value of living and non-living resources, which usually result in biodiversity functions and services being undervalued and underprioritized[3,4]. Additionally, there are stark inclusivity and equity issues associated with both types of resources[5]. A further complication is that the potential benefits of these resources for human well-being are both attached to somewhat uncertain and aspirational causal chains – deep-sea mineral resources may have the potential to feed green technologies and ultimately cause reductions in greenhouse gas emissions and a corresponding contribution to climate-change mitigation[6]. Similarly, a deeper understanding of marine genetic resources may inform nature-based solutions including climate-resilient resource management and conservation planning, while providing inspiration for novel biotechnology applications associated with reducing greenhouse gas emissions. Within this context of aspiration, uncertainty, inequity and complexity, transformational change is an urgent necessity to ensure a bright future for the ocean, its resources, and the people who depend on them.

Marine genetic resources

The history of life in the ocean is more than three times as long as that on land, starting some 3.7 billion years ago. During this time, life has evolved to thrive in everything from iconic tropical coral reef ecosystems to remote and understudied deep-sea ecosystems that feature conditions of extreme heat, cold, pressure, and absence of sunlight[2]. An estimated 2.2 million complex (eukaryotic) marine species exist, of which only 230,000 have been named and described by science, yet are likely outstripped in diversity by marine bacteria, archaea and viruses[6-10]. For instance, within the span of the last four years, the number of known marine viral populations increased by an order of magnitude from 15,000 to 200,000[11,12]. In addition to this vast biological diversity, there is also genetic diversity within populations, an important factor that can render species more resilient to changing ocean conditions, including to climate change[13-17].

Rapid technological innovations have opened the door to exploration of the ocean at a genetic level[18]. The average cost of sequencing a basic unit of DNA, for instance, fell within the past 20 years from over USD 6,000 in 2001 to around USD 0.01 today[19,20] (Figure 1). These advances have resulted in exponentially growing databases of genetic sequence data, most notably GenBank, which has been doubling in size every 18 months[21]. These databases have been an important resource for advancing taxonomic efforts, understanding the history of life in the ocean, and a growing array of marine biotechnology applications, including pharmaceuticals, genetically modified organisms, and industrial enzymes[22-24].

For a recent comprehensive review on marine genetic resources and associated equity issues, we refer readers to the High Level for a Sustainable Ocean Economy Blue Paper "The Ocean Genome: Conservation and the Fair, Equitable and Sustainable Use of Marine Genetic Resources"[18] and associated Review[2].

Mineral resources

The mining of metals and minerals has shaped humanity's development for thousands of years, yet conjectures of depletion of certain ores on land and projections for continuing increases in demand for some minerals for high-tech applications such as green technology and computers, have contributed to growing attention to deposits found in the ocean[25]. Of particular note are cobalt, copper, gold, lithium, nickel, silver and zinc, as well as rare-earth elements, with these deposits primarily found at extreme ocean depths in polymetallic nodules on abyssal plains, ferromanganese cobalt-rich crusts on seamounts, and polymetallic sulphides around mid-ocean ridges and back-arc basins (Figure 2)[25].

The majority of known deposits of polymetallic nodules and sulphides, with many cobalt-rich crusts also, are found outside of sovereign waters and falling under individual countries' ownership and management[26,27]. Thus, under the United Nations Convention on the

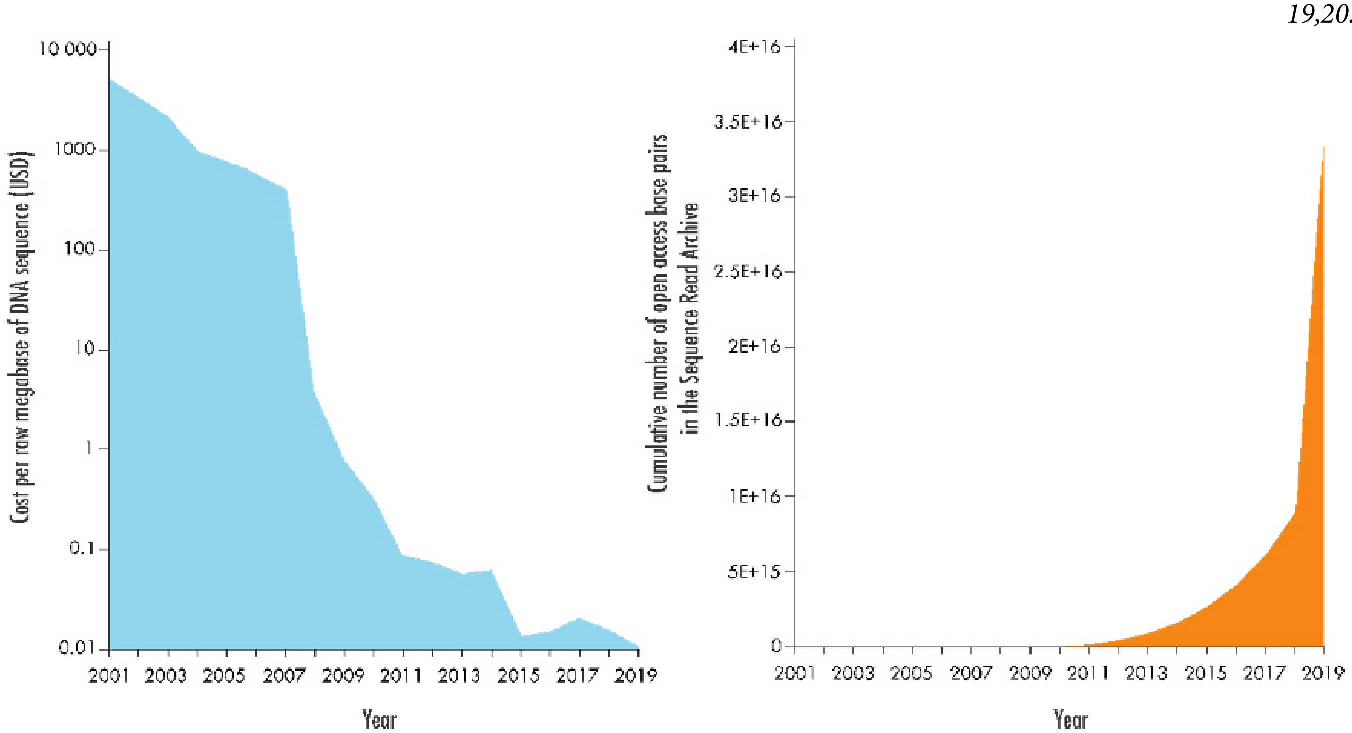


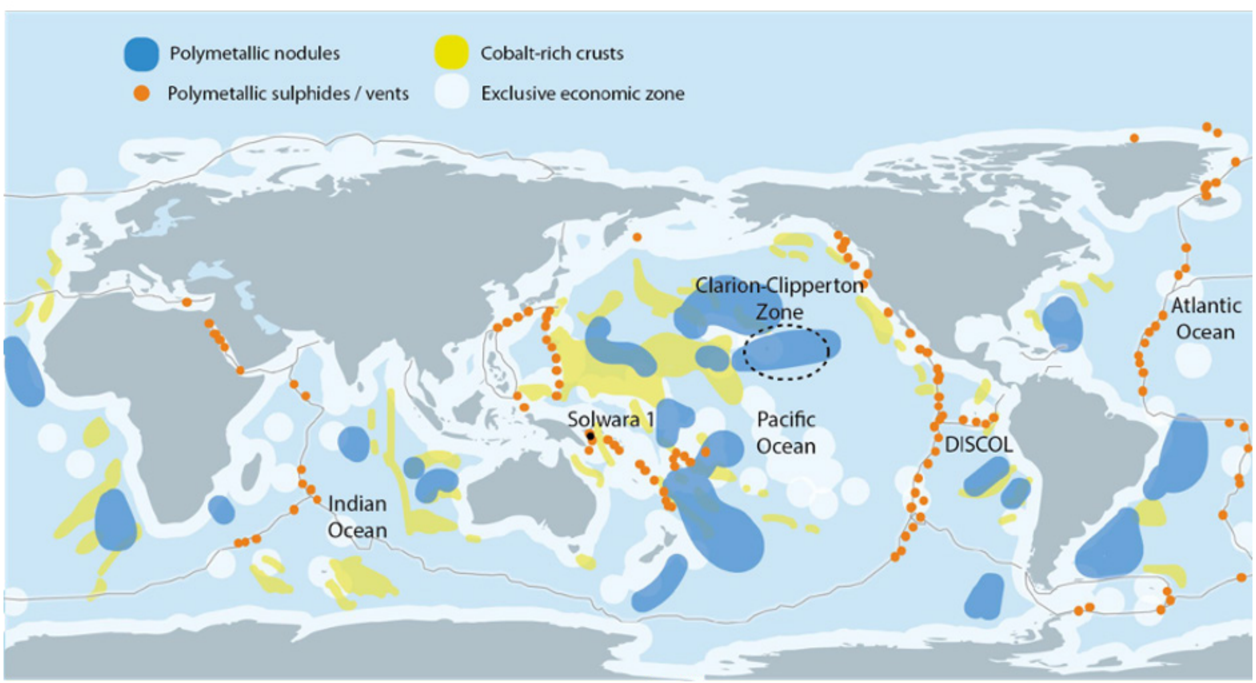
Figure 1: Sequencing costs and growth in the GenBank Sequence Read Archive. *A) Decline in average sequencing costs (cost per raw megabase of DNA sequence). B) Growth in the GenBank Sequence Read Archive (cumulative number of open access base pairs) 19,20.*

Law of the Sea (UNCLOS), these minerals are the common heritage of (hu)mankind, owned by all, and any mining activities are required to be undertaken (only) where this is deemed to be for the benefit of all of humankind; including through equitable distribution of any revenues raised. An intergovernmental body, the International Seabed Authority, is mandated to both regulate deep-seabed mining and ensure the protection of the marine environment from such activities[28]. To date, thirty contracts for seabed mineral exploration have been issued by the ISA, with some contractors now expressing an interest to move to an exploitation phase.

Deep concerns about the ecological damage that could result from commercial mining of the seabed are compounded by the limited basic knowledge of these remote ecosystems and the biodiversity and genetic resources within, or how they would react to industrial-scale disturbances[1,27,29]. Mining will involve the removal of the habitat for thousands of species, changes to the properties of the seafloor and seawater, an increase in contaminants, noise, vibration, and light, and the creation of sediment plumes that could considerably increase the human footprint in the ocean. This will likely lead to forced species migrations and the loss of biodiversity and connectivity, which could lead to the extinctions of species and the loss of ecosystem functions and services before they are known and understood[6,30-34]. Further concern stems from the inability of these ecosystems to recover on timescales shorter than millennia to millions of years. There are also further challenges related to the ethics, management, governance, and distributions of benefits for this nascent extractive industry, especially in an ocean increasingly shaped by climate change and other anthropogenic impacts[6]. If deep-seabed mining moves forward, it must be approached in a precautionary manner, so as to integrate new scientific knowledge and avoid and minimise harm to habitats, communities and functioning[25,28,32]. However, avoiding harm altogether is unlikely to be achievable given the destructive nature of deep-seabed mining[6].

For a comprehensive overview of the complex range of environmental, technological and equity issues associated with seabed minerals, we refer readers to the High Level for a Sustainable Ocean Economy Blue Paper "What Role for Ocean-Based Renewable Energy and Deep-Seabed Minerals in a Sustainable Future?"[6] and associated "Challenges to the sustainability of deep-seabed mining"[25].

Figure 2: Distribution of polymetallic nodules, polymetallic sulphides and cobalt-rich crusts in the deep sea[23].



Challenges in focus

Inclusivity, equity and accessibility: The remoteness of much of the ocean, particularly the deep sea, the shared ownership of its resources, the reliance of many developing nations and vulnerable communities upon the resources and health of the ocean, the unequal distribution of benefits and harms from much of its exploitation to date, and the costs of engaging in marine scientific or commercial activities, underscores the crucial importance of ensuring that all associated interventions actively seek to reverse existing inequities, and are built on principles of inclusivity. Proceeding without these will lead to further reinforcement of inequity in economic growth, social welfare, and the ability of nations to cope with the effects of climate change[5]. While the mineral resources of the international seabed are considered the common heritage of (hu)mankind, much remains to be done to ensure that decisions associated with the exploration and exploitation of these resources are informed by equitable and inclusive processes built on transparency and precaution[25]. Likewise, although genetic resources within national jurisdictions are subject to the access and benefit sharing framework under the Nagoya Protocol of the UN Convention on Biological Diversity, its full potential for supporting conservation and capacity building within "source" countries remains unrealized[2,24]. No corresponding regime exists yet for genetic resources from areas beyond national jurisdiction, although this is a key element of the ongoing negotiations on the international legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (BBNJ). In a global sense, very few countries are involved in commercial efforts associated with mineral resources from the international seabed (20 countries) or marine genetic resources (30 countries), and of these, even fewer are considered to be "developing countries" (11 and 2 countries for mineral and marine genetic resources, respectively)[24,25] (Figure 3).

Known unknowns: High aspirations and many unanswered questions come together in the deep sea. The potential for marine genetic resources to spur novel technological advances, including to combat climate change, depends on basic research, exploration and taxonomy with uncertain timelines and prospects for success[23]. With the majority of marine life still uncharacterized, quantifying the full value of intact deep-sea ecosystems for current and future generations is challenging (e.g., potential impacts to marine ecosystems as well as benefits and risks of deep-seabed mining to humankind).

Societal conflicts: Extractive industries have a chequered history, encompassing colonial exploitation, civil war, environmental devastation, and the 'resource curse'[35,36]. Deep-seabed mining, although not well known and not yet operational as an industry, is

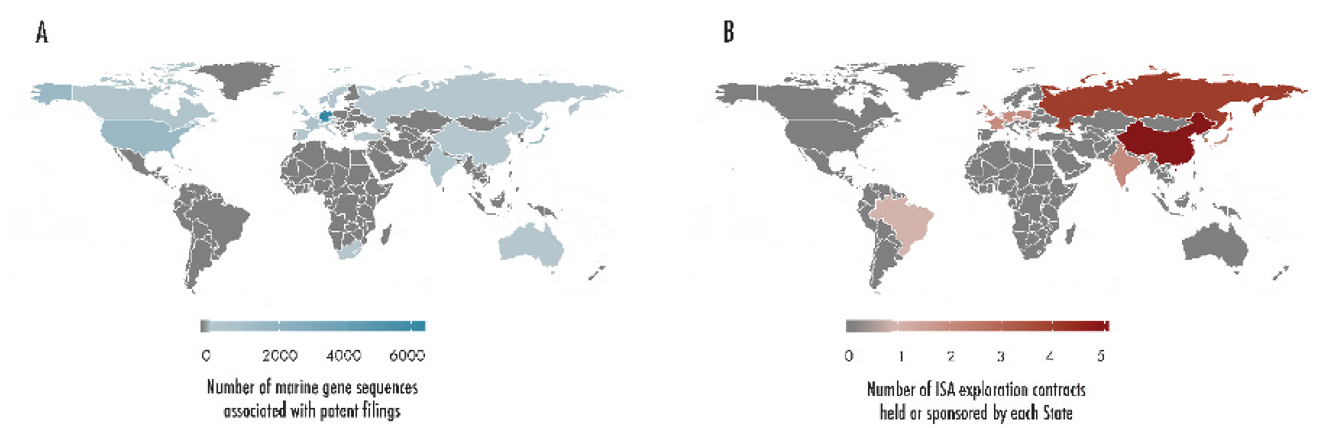


Figure 3: Countries involved in commercial efforts associated with (A) marine genetic resources (30 countries) * and (B) mineral resources from the international seabed (20 countries). *For a full list of countries and details, see References 24 and 25, respectively. *For (A), the European Union has 10 marine gene sequences associated with patents filings.*

already a highly polarized ocean issue. A prominent example of this is the conflict between proponents of deep-seabed mining as a source of minerals to fuel the green economy[37], and those concerned that extraction has the potential to impact adversely ocean health, including the ocean's role in climate regulation[38]. While all nations depend on the Earth's systems and benefit from a stable and predictable climate, the degree to which states are contributing to global greenhouse gas emissions, their relative vulnerability to climate-change impacts, their potential benefits from deep-seabed mining, and their voices within relevant international forums all vary widely.

Transformational Opportunities: Overview

The following section outlines eight Transformational Opportunities (TOPS) that can enable a step-change in our understanding of the ocean's mineral and genetic resources, as well as their contribution to climate-change mitigation and adaptation. Collectively, these TOPS span the themes of ocean observation, exploration and analysis, as well as associated outreach, policy and financial mechanisms (Figure 4). Cutting across all nine opportunities is the call for innovative partnerships and an emphasis on the need for humanity's interactions with the ocean to be founded on commitments to equity, inclusivity and diversity.

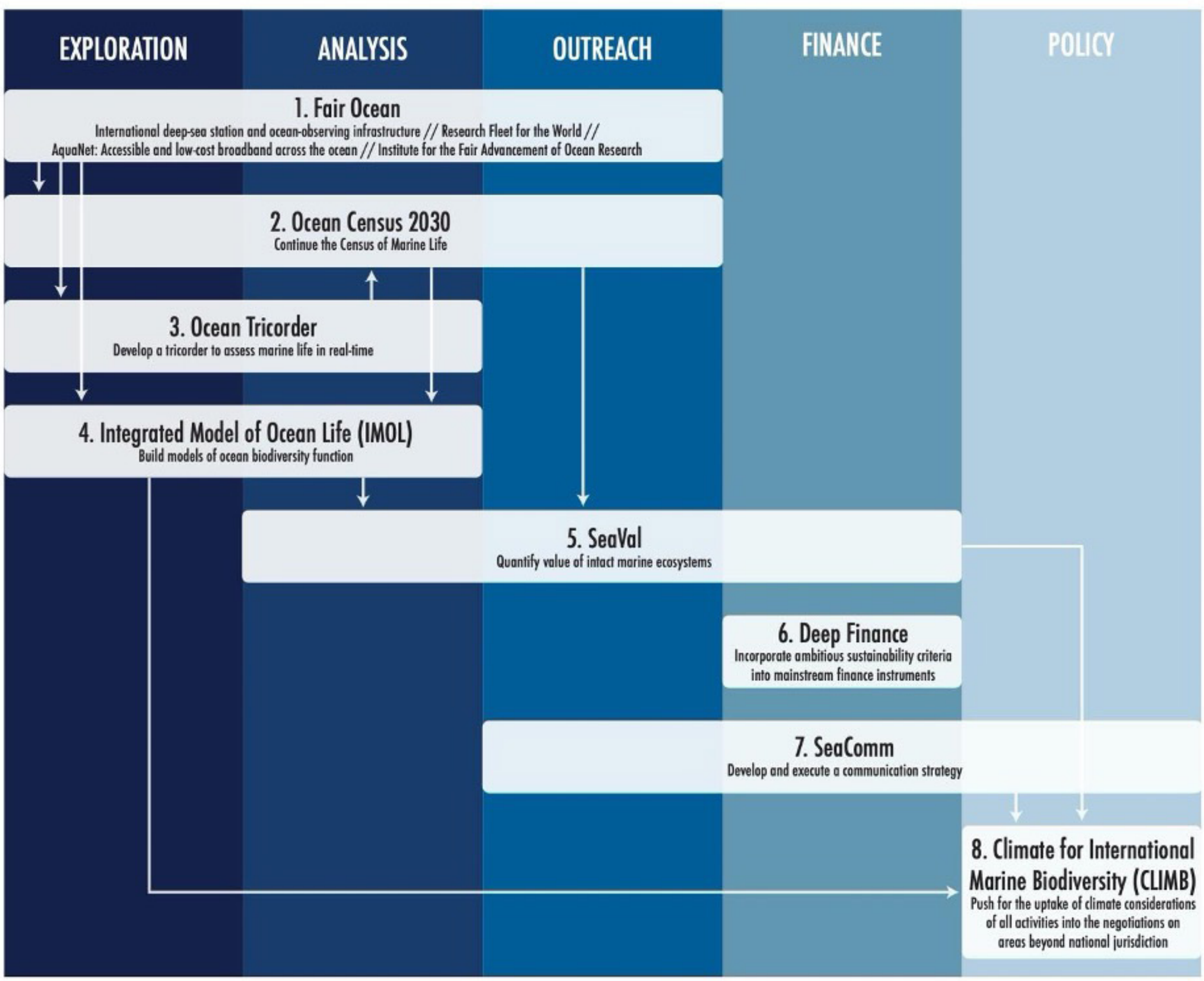


Figure 4: Thematic overview of Mineral and Genetic Resources Working Group Transformational Opportunities.

However, the majority of the TOPs are anchored in the need for an increased understanding of these resources. This will only be possible with more focused marine scientific research and as such several science TOPS have been proposed below. However, in order for these TOPS to be executed and then be integrated into deep-ocean management so that marine genetic resources are not jeopardized, slowing the transition process from deep-seabed mining exploration to exploitation is likely necessary[6,25].

Transformational Opportunity 1: Fair Ocean

Brief description: Establish integrated marine research and education infrastructure, based on promoting equity, inclusivity and diversity, to answer key scientific questions, bolster global capacity, and inform ocean policy:

(a) International deep-sea station and ocean-observing infrastructure;

(b) Research Fleet for the World;

(c) AquaNet: Accessible and low-cost broadband across the ocean;

(d) Institute for the Fair Advancement of Ocean Research.

Climate benefit	Medium
Co-Benefit	High
Return on Investment	Medium
Feasibility	Medium
Equity & Distribution	High
Risk	Medium
Sustainability or Longevity	Medium

(a) International deep-sea station and deep-sea observing infrastructure

The International Space Station has allowed our understanding of our solar system and beyond to expand substantially and has inspired millions of people worldwide. An analogous international deep-sea station should be established to inspire, and help us understand the deep sea, its rhythms over time and space, and its role in climate (see also TOPS 2, 3 and 4). One may question why a deep-sea station is attractive if the majority of marine life is found in shallow waters, but similar to the International Space Station, the deep-sea station is aimed not at exploring what is known and familiar, but actively seeking the unknown, where the greatest scientific advances are waiting to be made[39]. Ideally, the station would be connected to a fleet of ocean-deployed vessels (e.g., autonomous and remotely-operated vehicles, buoys, gliders, and manned submersibles). State-of-the-art instrumentation (see TOP 3), open-source data sharing and the promotion of diversity, equity, and inclusivity would be guiding principles.

It may be beneficial if this station, similar to the International Space Station, is not fixed, thus allowing exploration of a range of ocean locations. Alternatively, if fixed, commercial infrastructure could be leveraged by attaching deep-ocean observation nodes to regular subsea communications cables, thus allowing the international deep-sea station to fit into a broader deep-sea observing infrastructure[40] These nodes can be designed, structured, and located based on local requirements and emerging technologies and integrate various remote sensing platforms and systems. This simultaneously lowers the cost of installation and enables transmission of data in real-time to help better inform climate models. Both the international deep-sea station and associated observing infrastructure could be placed strategically, including, as suggested by the Deep-Ocean Observing Strategy (DOOS), in the Clarion-Clipperton Zone in the subtropical East Pacific, part of the international seabed where 16 exploration mining contracts have been issued by the ISA[27].

(b) Research Fleet for the World

Many countries are unable to fully access and explore the ocean because of a dearth of and high costs associated with appropriate vessels (Figure 5), hampering efforts to conserve and sustainably use marine resources[41]. By commissioning and/or repurposing a range of vessels that can be positioned strategically globally, exploration can begin to be undertaken by individuals from neighbouring countries or adjoining regions. Priority should be given to research teams led by scientists in countries with limited or no research-vessel capacity. All data associated with and collected during research cruises by vessels in the Research Fleet for the World would be made openly available in due course and fed into relevant platforms such as OBIS and the GenBank Sequence Read Archive. The Research Fleet for the World would encompass not only manned research vessels and submersibles, but also, as appropriate, gliders, buoys, floats, autonomous underwater vehicles., etc. In addition to new vessels, the Research Fleet for the World could provide an umbrella for existing research vessels funded by philanthropy[42] as well as dormant boats under private ownership.

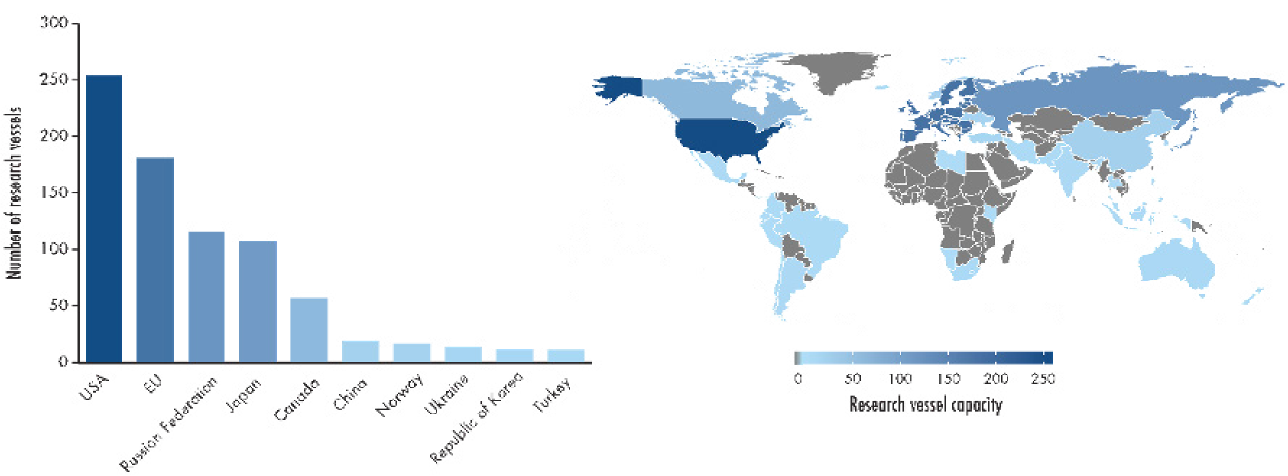
(c) AquaNet - Accessible and Low-Cost Broadband Across the Ocean

A lack of connectivity is one of the hurdles to achieving greater inclusivity and more diverse participation in everything from international policymaking to educational and capacity building programs, research initiatives and access to ocean data, and broad public engagement. COVID-19 has shown us how much can be achieved through connectivity by being more innovative, with much greater progress possible with further investment. AquaNet would prioritize low-cost and reliable wireless access for coastal communities around the world through increases in subsea telecommunication cables and new satellite technologies. Furthermore, this system could be enhanced by attaching ocean sensors to subsea telecommunication cables to deliver real time ocean data access e.g., allowing for better hazard warning (e.g., hurricane, tsunami) especially in remote locations. AquaNet links the most advanced ocean sensing to the communities most in need of it and, in the process, gives them a voice in the design and delivery of an inclusive and sustainable ocean information system.

(d) Institute for the Fair Advancement of Ocean Research

Many of the most marine biodiverse countries in the world lack the technical and financial capacity for marine exploration, thus are unable to reap the benefits including its use[41]. This transformative idea would see the development of a global institution that would actively promote large-scale, fair, interdisciplinary collaboration between high-income and low-income countries for the co-production of knowledge, co-discovery, co-cataloguing, and co-stewardship of biodiversity. The Institute would have science advancement and capacity development as interwoven core missions. It would also facilitate the study of marine biodiversity, ecosystem processes and the development of ocean-based solutions by placing the stewards of these areas front and center. Distance-learning technologies are becoming increasingly effective, and the Institute would mobilize these (in collaboration with AquaNet) to create an online global platform that could assist with broadening access, including to centralized and

Figure 5: Uneven current distribution of research vessel capacity (data from International Research Vessel Database)



accessible data. One of the Institute's mandates would be a commitment to raising awareness of ocean issues and increasing ocean literacy amongst a wider group of stakeholders including the public and policymakers (with potential linkages to TOP 7).

Potential benefits:

- The ocean is global, so those who are able to explore and study it should also be actively promoting diversity and inclusivity in marine science. This is an urgent necessity and will form the basis for not only accelerating principles of fairness and equity in international collaborations and the co-production of knowledge, but also the long-term development of truly global capacity and expertise in marine science.
- The deep-sea station, research fleet, AquaNet and Institute, will collectively provide an opportunity to achieve a deeper understanding and connection to the ocean, train new ocean leaders, significantly advance exploration and understanding of ocean ecosystems as well as associated processes, and provide diverse educational and awareness raising opportunities. It would also enable people around the world to join international conferences (where their voices have been previously absent) and engage in real time with international colleagues and collaborators.
- While the short-term contribution to climate-change adaptation or mitigation may be limited to an increase in observational data for climate models, over the medium to long-term, the Fair Ocean infrastructure will generate both data and a wealth of expertise that can substantially advance existing climate science by supporting a better understanding of the role of the ocean in climate and how it responds to change. Shorter-term benefits include data contributions to fisheries stock and production models, with the potential for countries to adapt and optimize fish and livelihood benefits from the ocean.
- The emergence of global networks of expertise via the TOP 1 infrastructure can accelerate the pace of discovery and research advances, stimulating a deeper sense of stewardship and engagement to foster transformative policies. This will include efforts to map marine genetic resources and to develop clear baselines and effective long-term monitoring of impacts of seabed mining and climate change.

Feasibility and Risks:

- Great interest has existed for some time in a deep-sea station[43], and the boldness of such proposals has broad appeal from a variety of stakeholders.
- Encouraging initiatives are already aimed, for instance, at donating vessel time for ocean science as well as promoting diversity and inclusivity in marine science. Through the Blue Climate Initiative, and in the spirit of the UN Decade of Ocean Science for Sustainable Development[44], there is an opportunity to massively upscale these individual successes.
- Some aspects of TOP 1 will be far more costly than others. The development of a standalone international deep-sea station, for instance, could require large sums of money[45]. However, it should be noted that it will almost certainly be less expensive than the International Space Station. Ensuring a realistic cost/benefit structure to ensure start-up and long-term longevity would be essential but difficult.
- In contrast, attaching observation nodes to underwater communication cables, or mobilizing fleets of autonomous drones and floats could carry much lighter price tags, while forming an integral part of the holistic TOP 1 infrastructure.
- A bold administrative and legislative structure with a "coalition of the Willing" support for these items of infrastructure, similar to that of the ISS, CERN, Human Genome Project, etc., will be required.
- AquaNet will mitigate the risk that the commercial and educational benefits of associated research efforts would be principally accrued by the world's most industrialized countries. Additionally, by branding local and coastal telecoms partners under the "AquaNet" label, providing them with technology, finance and other support it is feasible to rapidly increase coverage of areas that so far suffer from a lack of services.

- Construction of broadband infrastructure in remote areas of the ocean has environmental impacts and could spur greater human activity in pristine remote areas.

Transformational Opportunity 2: Ocean Census 2030

Brief description: Continue the Census of Marine Life to get organismal and genomic data on all marine species including microorganisms.

Climate benefit	Medium
Co-Benefit	High
Return on Investment	High
Feasibility	Medium
Equity & Distribution	Low
Risk	Low
Sustainability or Longevity	Medium

This TOP is inspired directly by the successes of The Census of Marine Life, a USD 650 million initiative from 2000-2010 that resulted in unprecedented global networks of collaboration among marine scientists. In total, more than 2,700 scientists from over 80 countries participated in 540 expeditions resulting in the discovery of 6,000 new species, some 1,200 of which were formally described by the time the project concluded. It fed over 30 million species incidence records into the Ocean Biodiversity Information System (OBIS), providing lasting benefits to countless ocean science efforts, and an important baseline for understanding climate-change and other anthropogenic impacts on the ocean. The Census also created an interactive community of deep-sea scientists that continue to collaborate, and can be mobilized to help enact many of the TOPS.

Ocean Census 2030 would build on these experiences, in conjunction with the UN Decade of Ocean Science for Sustainable Development 2021-2030, with a new decade of efforts aimed at continuing the Census of Marine Life and collecting organismal and genomic data on all marine species, including microorganisms. These efforts would require access to the deep sea for sample collection (see TOP 1), repository access for open-access storage, and standardized methodologies and protocols. The Ocean Census 2030 would convene a diverse and inclusive panel of experts (building on the networks established within the original Census of Marine Life) to identify, in a stepwise fashion, priority locations for attention, including understudied areas such as the deep sea, the microbial ecosystem services/genetic resources found on seabed minerals, or ecosystems characterized by high numbers of species that produce bioactive compounds of interest to medical science (see TOP 4). The Ocean Census 2030 would seek broad participation (e.g., through citizen science) to build collaborative networks and interest in marine science and the ocean around the world (see TOP 1).

Potential Benefits:

- A deeper understanding of marine ecosystems and the distribution of marine species would inform marine conservation measures and how climate change and other anthropogenic impacts are affecting marine life.
- This would also aid valuation of ecosystem services (see TOP 5).
- The influx of new genetic sequence and genomic data to GenBank and other global open-access databases could accelerate the discovery of promising bioactive compounds for biotechnology applications such as the development of new antivirals or antibiotics for human use or provide solutions to other societal problems (e.g., CO2 scrubbing).

Feasibility and Risks:

- Regulatory issues associated with collecting and sharing genetic sequence data from species collected within national jurisdiction remain unresolved (in the context of the Nagoya Protocol) as well as in areas beyond national jurisdiction (ABNJ) in the context of the BBNJ negotiations.
- Most of the technical capacity and necessary infrastructure resides with wealthy countries, and the original Census was led by these. Extra effort would be required to ensure, e.g., through the TOP 1, that the Census efforts are inclusive, provides equitable opportunities, and builds capacity among all countries.

- Unlike the other TOPS, this one is timebound, meaning that the sustainability dimensions are somewhat different and primarily linked to whether or not the formation of new collaborative networks and research infrastructure around the world persists following the conclusion of the Ocean Census. Experience with the first Census of Marine Life can be leveraged in this regard.
- The decade to 2030 is already being shaped by the Sustainable Development Agenda and the UN Decade of Ocean Science for Sustainable Development, and in order for this TOP to further contribute to these efforts, there may be a need for novel funding sources that do not result in diminished resources already allocated to these decade-long efforts.

Transformational Opportunity 3: Ocean Tricorder

Brief description: Develop a tricorder that can assess marine life in real-time, including at a genetic level to lessen dependence on the infrastructure, equipment and other resources associated with sampling/collecting and transporting samples for later sequencing and analysis.

Climate benefit	Low
Co-Benefit	High
Return on Investment	Medium
Feasibility	Medium
Equity & Distribution	Low
Risk	Medium
Sustainability or Longevity	High

Understanding biological processes in the ocean is essential to mapping out their roles in biogeochemical cycling and contributions to ecosystem services. A key technical gap, in the ocean as well as other environmental settings, is the lack of a widely-adopted method for remote and real-time detection of microbial community composition and function, especially given our lack of understanding of them. However, this also extends to biological communities at large, although many emergent technologies may help address this issue. An "Ocean Tricorder" - like the science-fiction tricorder of the Star Trek universe that can quickly assess properties of interest in real-time - would not only benefit scientific understanding of ecosystems, but has the potential to motivate new technologies that would be highly valuable for resource managers and offshore industries. We propose that as a first step in the development of the tricorder, we organize a conference to bring together diverse experts in microbiology, ecology, and chemistry with leaders in genomic, computational, sampling, and engineering technical innovation to collectively envision method(s) for the real-time assessment of microbiomes in aquatic ecosystems. Following this, steps can be taken by relevant teams to take the Ocean Tricorder from concept to prototype.

Potential Benefits:

- This will provide a step-change in the speed and scope of marine science, among other things, by decreasing reliance on sampling/collecting and transporting samples for later sequencing and analysis.
- This will increase our understanding of how the vast genetic biological diversity correlates with ecosystem function.
- This will also offer a profound technological advancement and could have wider applications, including on other planets.

Feasibility and Risks:

- The concept and benefits of a tricorder have captured the public imagination and have been an attractive communication tool for innovators, yet truly "real-time" assessment has proven elusive, although previous advances with restricted application have shortened the timeframe to days[46], and more recently two hours in the case of testing for antimicrobial resistance[47,48].
- This will require genetic biodiversity data gleaned by TOP 2 in order to be successful.

- Given the technological novelty of this endeavor, Ocean Tricorder is likely to be a much longer-term and aspirational TOP.
- Most of the technical capacity and necessary infrastructure resides within wealthy countries. Extra effort would be required to ensure, e.g., through TOP 1, that these efforts are inclusive, provides equitable opportunities, and builds capacity among all countries.

Transformational Opportunity 4: Integrated Model of Ocean Life (IMOL)

Brief description: Build models of ocean biodiversity function to understand the role of the oceans in carbon cycling and climate-change mitigation, among other things, to identify potential tipping points, what areas of the ocean are particularly critical in climate functions and services, and where interventions may be most successful in relation to both time and spatial scales.

Climate benefit	High
Co-Benefit	High
Return on Investment	Medium
Feasibility	Medium
Equity & Distribution	Low
Risk	Low
Sustainability or Longevity	Medium

This TOP will allow us to reframe our understanding of 'genetic resources' to better understand the deep ocean, its role, and the potential for it to provide nature-based climate solutions. This will be primarily done through large-scale ocean ecosystem modelling; however, this process will likely need to be refined and supplemented with the collection of new ocean data. To this end, modelers will work with other ocean scientists and stakeholders to develop a research agenda in alignment with the UN Decade of Ocean Science for Sustainable Development 2021-2030, which can be executed by leveraging resources in TOP 1 and be bolstered using new data gathered through TOP 2. This will increase our knowledge of the role of the oceans in carbon cycling and sequestration, and hence climate-change mitigation, which is currently overlooked and undervalued (see TOP 5). This would spur the identification and quantification of agents of carbon removal and sequestration as well as the development of novel technologies and nature-based solutions that can be harnessed to reduce other greenhouse emissions (e.g., extremophile life associated with methane seeps and/or CO2 vents that can capture and/or fix methane and carbon dioxide). To overcome barriers regarding inclusivity and equity, this research could be done in collaboration with TOP 1.

Potential Benefits:

- This has the potential for ocean-based innovative solutions to the buildup of greenhouse gases, with implications for the habitability and health of the planet and its people.
- This could increase the conservation of biodiversity and benefit sharing under the BBNJ instrument. This would mainstream the conservation of these resources including natural carbon sequestration and climate resilience in situ as part of climate-change adaptation and mitigation.
- Provides insights into the full economic valuation of ocean biodiversity and services (TOP 5).

Feasibility and Risks:

- This research is highly feasible but will be of moderate cost given the expense of deep-sea research.
- Many of the findings will involve genetic resources within and beyond national jurisdiction leading to benefit sharing/access issues similar to those described above for the Ocean Census 2030.
- Most of the technical capacity and necessary infrastructure resides with wealthy countries. Extra effort would be required to ensure, e.g., through the TOP 1, that these efforts are inclusive, provides equitable opportunities, and builds capacity among all countries.
- The usefulness of models is dependent on the quality of input data, and over time, gaps in ocean observations could undermine the long-term benefits

of such models as ocean conditions change, underscoring the need for the Fair Ocean infrastructure (TOP 1).

Transformational Opportunity 5: SeaVal

Brief description: Holistically quantify the value of intact marine ecosystems and the services they provide, including carbon cycling and climate-change mitigation.

Climate benefit	High
Co-Benefit	High
Return on Investment	High
Feasibility	Medium
Equity & Distribution	Meduim
Risk	Low
Sustainability or Longevity	High

Management and policy decisions, as well as consumer behavior, are all associated with perceptions of value. A narrow or sectoral focus on commercial value only can yield short-sighted and damaging outcomes. Holistic approaches to quantifying the range of services (or "nature's contributions to people"[49]) provided by intact marine ecosystems have represented a significant challenge since the emergence of ecological economics[50], and a lack of such approaches has hampered ocean stewardship within international policy as well as national management decisions. SeaVal would fill this gap by convening a diverse body of expertise to holistically synthesize existing knowledge of ecosystem services and identify gaps. This would then allow for a program that investigates and quantifies the value of marine ecosystems such as for carbon cycling (and hence, climate-change mitigation), and many other services provided by the natural capital of the deep ocean[4]. After which, more informed decisions will be possible.

Potential Benefits:

- Quantifying the value of intact and degraded marine ecosystems now and into the future, as well as who that value accrues to (or is lost from), will provide a powerful tool for policymakers to take informed decisions about activities that have the potential to disrupt those areas.
- Great economic-based insights may assist policymakers to prioritize conservation and sustainable use of marine resources and yield compelling data for incorporation into international negotiations on climate and ocean issues (see TOP 6).

Feasibility and Risks:

- A constant concern about valuing nature, particularly when it is not already fully protected, is that this may not fuel conservation efforts, but rather renewed focus on extraction or use. A holistic valuation framework, however, mitigates this risk somewhat as much of the value would be associated with regulating services, and the narrow sectoral values of, for example, commercial fish populations or mineral resources are already known.
- There is an increasing willingness to undertake this type of action, but one of the biggest challenges is the lack of understanding of the deep ocean, its functions and what roles organisms play in this – and how to translate this into value judgements. This would require further research in line with TOPS 2 and 4.
- SeaVal's contribution to reducing existing inequities would rest on its capacity to fully integrate multiple values of ecosystem services into its methodology by encompassing a diversity of cultural values and perceptions[4,51,52]. There are non-monetary values that pertain to the deep sea (cultural, spiritual, existence and future values) that are difficult to weigh in traditional cost-benefit analyses. A methodology is needed to consider monetary and non-monetary values alongside each other.

Transformational opportunity 6: Deep Finance

Brief description: Incorporate ambitious sustainability criteria into mainstream finance instruments associated with use of the ocean's mineral and genetic resources.

Climate benefit	High
Co-Benefit	High
Return on Investment	High
Feasibility	Medium
Equity & Distribution	Meduim
Risk	Low
Sustainability or Longevity	High

Deep-sea exploitation at scale will require significant investment. In addition to strict regulation of these activities, it is important that external finance provision (be it loans, equity, insurance, etc.) is likewise handled in a way that encourages sustainable practices. Innovative financial instruments can help to drive a more sustainable blue economy[53,54], but limited attention has been directed towards existing mechanisms that account for the bulk of corporate financing[55]. Banks in particular hold potential for promoting sustainability given their ability to engage in detailed monitoring of a company and to tailor loan terms. Strict loan covenants can be used to ensure the borrower implements appropriate measures and be used to reward those with good practices[a]. There are already examples of sustainability criteria incorporated in commercial loans and a range of relevant performance standards and principles, such as the International Finance Corporation performance standards, the Equator Principles, the European Investment Bank Environmental and Social Standards and Blue Economy Sustainable Finance Principles. However, these standards need to be tailored to ocean extractive activities, be strictly enforced and a formal precondition to any deep-sea exploration activity.

Potential Benefits:

- By incorporating strict, ecosystem-based sustainability criteria into loan covenants and binding companies to environmental risk assessments, reduction in CO_2 emissions as well as nitrogen and phosphorus pollution, establishment of science-based targets, commitment to preserving specific areas, disclosure of marine genetic resources' origins, etc., banks could play their role in supporting responsible use of the ocean mineral and genetic resources and accelerating transformation towards better practices.
- A radical and deliberate transformation of how sustainability is integrated into traditional financial services – either at their own initiative or via regulation – would also improve the effectiveness and efficiency of financial institutions with respect to the materiality of non-financial information.
- In turn, the company's social and environmental performance will yield both financial and reputational benefits.
- This Transformational Opportunity is likely to be relevant and applicable across multiple Working Groups and could be seen as the basis for synergies, collaborations and substantial co-benefits.

Feasibility and Risks:

- The mechanisms (e.g., credit lending) are already in place yet the criteria that are being considered need to be strengthened, in particular non-financial information. This will require significant capacity building, driven by financial regulators and central bank coordination. Transformative potential is realized as financial institutions become (i) more appreciative of how environmental risks are likely to translate into financial and reputational risks, and (ii) willing or compelled to transform their own practices toward improved sustainability, which requires a behavioral and societal shift.

a For example, the agriculture giant Louis Dreyfus Company recently agreed with its lenders a $750 million loan for which the interest rate is linked to the company's sustainability performance, as measured by a reduction in its carbon dioxide emissions, electricity consumption, water usage, and solid waste sent to landfill.

- The information provided by the companies also needs to be independently audited to ensure its validity and reliability. Pressure from civil society organizations and the general public will be important to promote awareness and stimulate regulatory responses.
- Where it is not yet the case, national and international regulation regarding financial reporting and accounting must be expanded to also include relevant non-financial information. Governments need to enforce this type of reporting by treating it on par with the requirements of financial accounting and reporting standards.
- There is growing momentum around green/blue finance with numerous initiatives that could inform and support such transformation[b]. There is also an opportunity here for timely intervention, as seabed-mining companies are likely to be exploring financing and other banking guarantee and insurance instruments in the near-term, for the first time.

Transformational Opportunity 7: SeaComm

Brief description: Develop a communication strategy and associated high-quality movie or series focused on the deep ocean and associated anthropogenic issues. This will raise awareness, leading to increased stewardship.

Climate benefit	Low
Co-Benefit	High
Return on Investment	High
Feasibility	High
Equity & Distribution	High
Risk	Low
Sustainability or Longevity	High

Much of the ocean and the life it contains is remote from the daily human experience, posing a challenge to communicating the importance of the ocean for the climate and biosphere, as well as its direct and indirect contributions to human well-being[56]. Capturing public interest in deep-sea ecosystems, issues surrounding mining of the international seabed, and associated climate change issues poses a particular challenge[57]. This TOP would involve mobilizing the expertise of scientists, science communicators, media experts, and public relations companies to develop an innovative global communications campaign ("SeaComm") that packages these issues in a compelling manner for an international audience. By raising awareness about the deep sea, its resources, its possibilities, and inspiring humankind, there is a real possibility to affect change from the bottom up and the top down.

The appeal of documentaries as a communications tool has grown increasingly apparent with the impact of series such as BBC Planet Earth, Blue Planet II, and Our Planet[58-60]. One element of SeaComm would be the development of a dedicated blue-chip/high-quality movie or documentary series specifically focused on the deep ocean and anthropogenic impacts, as well as to promote transitioning to a less-impactful circular economy.

Another element would be a toolkit to mobilize awareness and inform the public of the risks and benefits of seabed mining in areas beyond national jurisdiction, as well as specific ocean issues that they should be able to weigh in on via their governments. This is key as thus far the public has been largely excluded from decision-making. An example of this is to bring public attention to the discussion around royalty rate at the International Seabed Authority, and seek views on whether 2-6% of the minerals value is deemed a fair exchange price for the loss of valuable assets, and associated environmental damage, that humankind will suffer as a result of seabed mining beyond national jurisdiction. Engagement with this topic could ultimately build consensus via governments that the transition from "exploration" to "exploitation" should not occur unless certain pre-agreed conditions were met. The tool-kit could include age-appropriate materials targeted at young people, and packaged in a way that can be used within school curricula globally.

b For example, The Sustainable Blue Economy Finance Principles, The Principles for Responsible Banking, and The Task Force on Climate-related Financial Disclosures.

Potential Benefits:

- Acting as a catalyst to reach a tipping point in behaviour among consumers and policymakers alike, SeaComm will help bridge negotiating spaces: contributing to renewed emphasis on the ocean in international climate negotiations, and to the mainstreaming of climate issues into ocean negotiations (see TOP 8).
- Communicating the importance of the deep ocean can carry diverse co-benefits with regard to biodiversity conservation, as well as social and economic dimensions of equity.
- Benefits of SeaComm may be difficult to conclusively attribute, but are expected to contribute to shifting of norms and values, in line with the theory of social tipping points, leading to meaningful behaviour change[61].
- Engaging all of humankind to generate increased societal awareness of the choices associated with deep-seabed mining, especially those resources that are the common heritage of humankind, and broader stakeholder input at the domestic and international level indicating 'a social license to proceed'.

Feasibility and Risks:

- The development of SeaComm and an associated documentary series or movie is highly feasible, and models can be found that emphasise individual agency e.g., the episode of Blue Planet II that has been associated with renewed focus on ocean plastic-pollution issues.
- Issues surrounding mining of the international seabed are sensitive, and the effectiveness of SeaComm would rest on its ability to fairly and effectively portray these issues, as well as potential solutions, to a diverse audience. Perceptions of advocacy or bias could undermine its broad effectiveness.
- Operating in the deep sea is costly, and the price tag for such a film or documentary series would be high, however the return on investment and associated co-benefits are expected to be favorable.

Transformational opportunity 8: Climate for International Marine Biodiversity (CLIMB)

Brief description: Push for the uptake of climate considerations of all activities into the negotiations on the Mining Code for the seabed beyond national jurisdiction, and the international legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction. Additionally, evolve a method for developing and reporting on mitigation and adaptation goals across all sectors operating in ABNJ.

Climate benefit	High
Co-Benefit	High
Return on Investment	High
Feasibility	Medium
Equity & Distribution	High
Risk	Meduim
Sustainability or Longevity	High

ABNJ cover some 64% of the ocean, a vast area of global importance for the climate and biosphere. Ocean currents as well as the migratory paths of many marine species extend across national jurisdictions and ABNJ, making these remote areas ecologically connected to coastal ecosystems and communities around the world. The ocean plays a major role in regulating the planet's climate, absorbing massive amounts of heat and CO2 from the atmosphere; a function that relies on a healthy ocean. Climate change is causing warming, stratification, ocean deoxygenation and ocean acidification in ABNJ, including in the deep sea, with consequences for the production, distribution and diversity of marine life[62]. Furthermore, multiple commercial activities are pursued in ABNJ, primarily fisheries, shipping, laying of seabed cables, and exploration (and potentially exploitation) of mineral resources; these may be affected by or influence climate change[63]. There is a significant gap in climate regulation, as the UNFCCC (the global treaty aimed to reduce greenhouse gas emissions) primarily addresses activities that take place in areas within national jurisdiction, while activities that take place in ABNJ are typically regulated by multiple sectoral regimes, not all of which are currently linked to the UNFCCC in a formal manner.

A legal framework for the conservation and sustainable use of biodiversity of ABNJ is under negotiation, but climate considerations are limited in the current draft. Climate issues need to be considered as healthy oceans are of key importance for mitigating climate change (see TOP 4).

The ISA is developing the Mining Code, setting the rules for deep-seabed mining beyond national jurisdiction, but climate considerations are limited to brief mentions (but not restrictions) of greenhouse gas emissions in the current draft.

The International Maritime Organisation (IMO), the body responsible for setting shipping standards, has begun to adopt some measures seeking to restrict greenhouse emissions from ships, which will commence in 2023. But these will rely upon individual States for reporting and enforcement mechanisms, and the links between these measures and marine biodiversity (e.g., reduced underwater noise, reduced whale strikes from slower ship speeds) are not readily apparent in the current draft of the IMO strategy. Should climate geoengineering activities be adopted that involve the introduction of chemicals into ABNJ, the IMO would also regulate these.

The FAO has issued international guidelines for the management of deep-sea fisheries in ABNJ, which apply to States and regional fisheries management organisations. Current practices (which encompass EIA and Vulnerable Marine Ecosystem designation) do not consider climate change.

The Climate for International Marine Biodiversity (CLIMB) Transformational Opportunity would seek to mainstream climate-change mitigation and adaptation into all human activities in ABNJ, by integrating consistent requirements for climate considerations through the various relevant negotiations and fora, including the BBNJ text, ISA rules currently being negotiated for seabed mining activities, FAO guidance for fisheries, and IMO instruments pertaining to shipping. This would call for all commercial activities in ABNJ, to explicitly include climate considerations in their operations, not least through tailored tools and protocols for adapted use of strategic environmental assessments and environmental impact assessments[c], as well as in spatial management (protected area design) and conservation planning. CLIMB could foster the development of objectives, guidelines and criteria that promote climate-change mitigation and adaptation, that could be adopted by all actors in (or influencing) ABNJ. This could be supported by a reporting method for ABNJ (equivalent to the Paris Agreement nationally determined contributions) with input from all States having activities in or influencing ABNJ. Such reporting would inform both the UNFCCC (which has relevance to ABNJ in terms of transboundary climatic impacts on ABNJ from activities in areas within national jurisdiction as well as climatic impacts from activities in ABNJ that are under the jurisdiction or control of Parties), as well as the various sectoral bodies/international organisations overseeing relevant activities, and the BBNJ instrument (whose scope is potentially expansive enough to include both activities in ABNJ as well as activities in areas within national jurisdiction that have climatic impacts on ABNJ). Ideally, each sectoral body/international organisation would require the report from its member States (using a consistent protocol), and then each of those bodies would in turn collate and share that information via the UNFCCC process. Such a protocol would work closely with all actors to ensure there are clear mechanisms in place to validate, monitor and operationalize commitments. CLIMB would serve to spur a broader understanding between overlapping sectors and avoid climate issues falling between the gaps of different multilateral processes (e.g. highlighting linkages between BBNJ, the ISA, and FAO, with the IMO's greenhouse gas reduction strategy, bringing focus to climate benefits, and biodiversity co-benefits).

c "SEA is a core component of strategic assessments that may take place across a whole sector (e.g., at the scale of an entire mineral province) or across a whole terrestrial or marine sub-region (e.g., at the scale of catchments or large marine ecosystems) while EIA is customarily applied to a single development, project, initiative or action."[64]

Potential Benefits:

- Commercial activity in the ocean is rapidly increasing, including in ABNJ. Including climate considerations in these activities would serve as both a recognition of the role that the ocean plays for the Earth's climate, and as an incentive to reduce emissions and increase climate resilience in ABNJ, with flow-on benefits to associated ecosystem services.
- Better incorporation of climate considerations into the ISA's regime now, while exploration contractors are conducting scientific research to characterise the areas of the seafloor before any mining commences, could provide a unique opportunity to build a scientific baseline for understanding future climate effects.
- Could bring over 60% of the ocean under a cohesive global approach to climate reporting.
- Co-benefits include positive benefits for marine biodiversity in general, providing climate refugia for various marine life, enhancing the overall marine food web, and safeguarding the cultural values associated with marine biodiversity.

Feasibility and Risks:

- Efforts to mainstream climate issues in a substantial way within the BBNJ and ISA negotiations and within IMO and FAO could face resistance, among other things due to the existence of associated non-binding options, or due to sectoral silos across intergovernmental agencies.
- While climate issues are inarguably important, adding a new focus into ongoing negotiations has the potential to further slow progress and distract attention from other sticking points in the negotiations.

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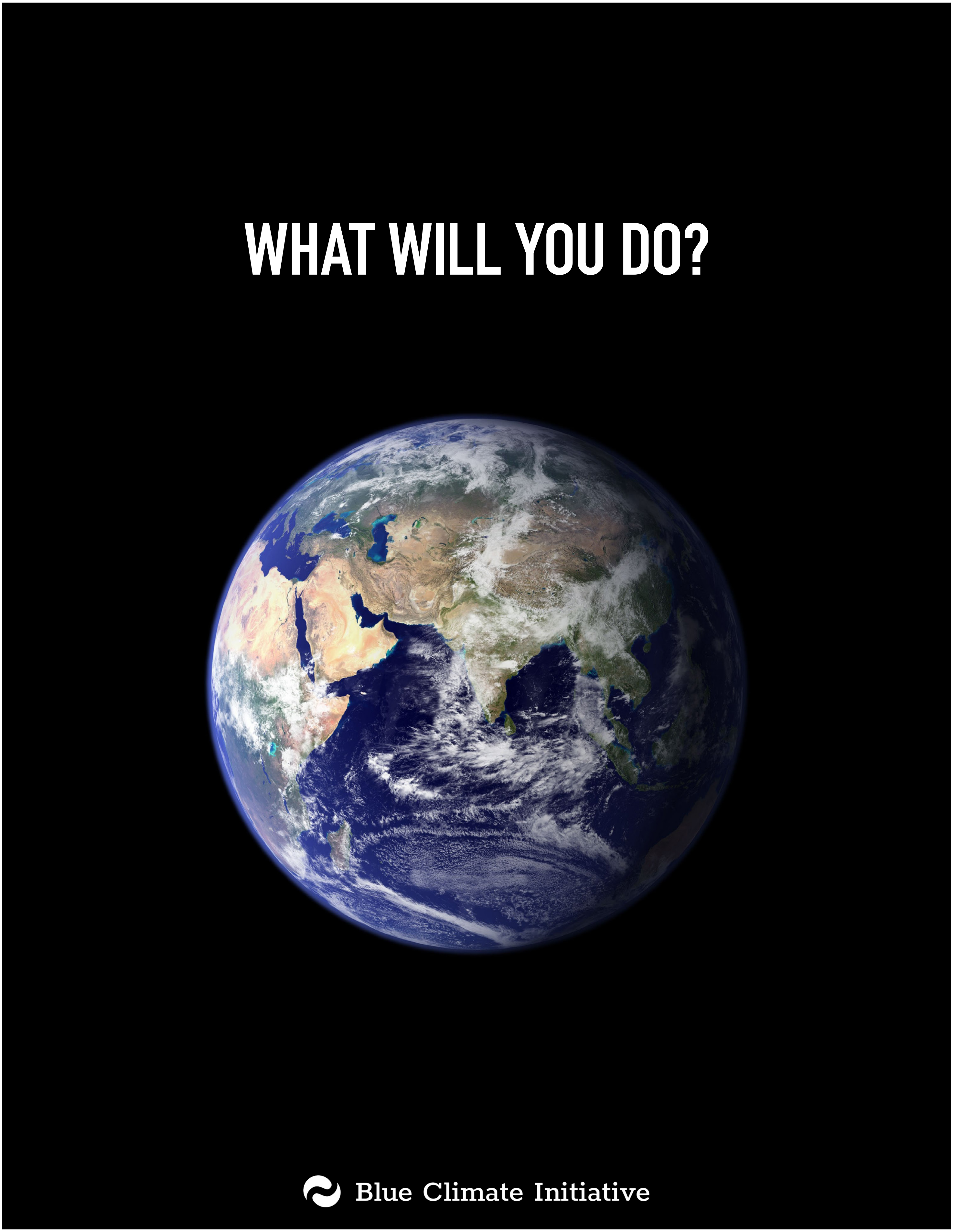
- Clement Yow Mulalap: Legal Adviser, Permanent Mission of the Federated States of Micronesia to the United Nations.



The Blue Climate Initiative accelerates ocean-related strategies, collaborating across a multidisciplinary global community towards a restored and healthy climate; an understood and protected ocean; and resilient, thriving and equitable communities. The fiscal sponsor for the Blue Climate Initiative is Tetiaroa Society, a US 501(c)(3) nonprofit organization (tetiaroasociety.org).