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Digital Oceans:
Open Data

FALL 2021

GOOD DATA INITIATIVE

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DIGITAL OCEANS: OPEN DATA

OCTOBER 2021

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GDI **REVIEW**

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The global ocean: a huge body of saltwater that, despite covering 70% of our planet's surface, remains more than 80% unobserved and unknown (NOS, 2021). Yet, the increasing proliferation of new marine technologies is now enabling an unprecedented scale and speed of oceanic exploration and digitization — and with it, the generation of extremely valuable data.

Most new ocean data, however, remains privately held and unavailable to researchers, governments, or the public. Existing datasets may be publicly available, but are often of vast quantities and varying qualities, and require resources and expertise to unlock and analyse. Given the importance of the ocean, how might we change these data practices to improve our knowledge and stewardship of this unique environment?

In this review, members of the GDI team dove deep to identify the crucial gaps in ocean data preventing the accurate assessment and understanding of marine ecosystems and human impacts on them. By analyzing key stakeholders and selected case studies, this study identifies the importance of mobilizing inter-sectoral collaboration in generating, unlocking, and providing open access to ocean data — enabling us to better understand the essential role that oceans play not only in our daily lives, but in tackling the climate and biodiversity crises our planet faces.

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DIGITAL OCEANS: OPEN DATA
GLOSSARY

ABNJs	Areas Beyond National Jurisdiction
AIS	Automatic Identification System
AOGCMs	Atmosphere–Ocean General Circulation Models
'The Area'	Ocean floor and subsoil beyond the limits of national sovereignty
DELOS	Deep-ocean Environmental Long-term Observatory System
EEZs	Exclusive Economic Zones
FAIR	Findable, accessible, interoperable, and reusable [data]
GCMs	Global Climate Models
GFW	Global Fishing Watch
IOC	Intergovernmental Oceanographic Commission
IODE	International Oceanographic Data and Information Exchange
IPCC	International Panel on Climate Change
ISA	International Seabed Authority
MPAs	Marine Protected Areas
NOAA	National Oceanic and Atmospheric Administration
OBIS	Ocean Biodiversity Information System
RFMOs	Regional Fisheries Management Organisations
SDGs	UN Sustainable Development Goals
SIDS	Small Island Developing States
UNCLOS	The United Nations Convention on the Law of the Sea
VMS	Vessel Monitoring System

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DIGITAL OCEANS: OPEN DATA
INTRODUCTION

The oceans are vital to our planet. They contain vast biodiversity as well as significant stores of carbon. In addition to the valuable ecosystem services they provide, oceans are a crucial fount of resources for humans, ranging from fish to minerals to energy and more. Threatened by ever-increasing anthropogenic activities, understanding and sustainably managing the earth's oceans will be critical in tackling ongoing and future climate and ecological crises.

Despite covering 70% of our planet's surface, more than 80% of the ocean remains unobserved and unknown.[1] While human activities have expanded to the far reaches of the ocean, our scientific knowledge lags behind. We have less knowledge about the ocean floor than we do about the surface of the moon. In the deep ocean, the high seas beyond national oversight, and the vast (and largely unmonitored) regional seas spanning the Indian Ocean, fishing, mining, drilling, shipping, cable-laying, seismic exploration, and other human activities continue at pace while our understanding of their impacts remains limited, if not entirely lacking.

Knowledge about ocean ecosystems and the impact of human activities on them is required to ensure the sustainable stewardship of the ocean, as well as its services and resources, in support of the Sustainable Development Goals (SDGs). Gaps in environmental data prevent the effective implementation of monitoring of policies and of the SDGs.[2] Expert stakeholders agree that robust and appropriate monitoring and data *must* inform ocean management. In fact, establishing trustworthy, science-based data resources from all parts of the world's oceans is the aim of the recently begun UN Decade of Ocean Science.

A recent proliferation of data technologies offer the potential to provide this much-needed ocean data necessary to establish effective ocean monitoring and management. Remote sensing technologies create access and insight for researchers and the public into the far reaches of the ocean. However, although we are collecting more and more oceanic data, there remain significant gaps in the ocean data flow resulting in these data not being used. In short: we are not always collecting the data we need. Most data are not shared publicly or cannot be easily accessed. Existing datasets may be publicly available, but are often of vast quantities and varying qualities, requiring significant resources and expertise to unlock and analyse.

Given the remote, logistically challenging, and ungoverned nature of the seas, this report reviews an important way we might address key issues stopping the appropriate collection and analysis of ocean data: via inter-sectoral collaboration. All stakeholders have a role to play in effective ocean monitoring and stewardship through generating new sources of data, unlocking existing datasets, and making data available to communities, researchers, and policymakers so they may better fulfill their stewardship roles.

This review thus identifies three gaps in the state of ocean data that prevent adequate assessment of ocean ecosystems and the impacts of human activities on them. While a full audit of the state of oceanic data is beyond the scope of this review, this methodology provides insight into key gaps in data and their causes. By analysing key stakeholders and selected case studies, this study identifies the importance of mobilizing inter-sectoral collaboration to generate, unlock, and make available ocean data. To draw out these opportunities and lessons, this review culminates with key recommendations for each relevant stakeholder group.

While the oceans are becoming explored and digitized, they are also being increasingly exploited. It is the firm belief of the authors that we must harness these innovations to generate and make available the ocean data required to establish effective monitoring and stewardship of the ocean in the face of unprecedented anthropogenic threats.

[1] National Oceanic and Atmospheric Administration US Department of Commerce, 'How Much of the Ocean Have We Explored?', accessed 3 May 2021, https://oceanservice.noaa.gov/facts/exploration.html.

[2] United Nations News, ' SDGs: Greater urgency needed to meet environmental goals, improved data likely key,' 22 May 2021, https://news.un.org/en/story/2021/05/1092532

SECTION 1:
IDENTIFYING DATA GAPS

INTRODUCTION

As highlighted in the introduction to this report, significant and persistent gaps exist in ocean data.[3][4][5] Given the importance of first understanding these gaps before we seek to remedy them, this section of the report (1) outlines the major existing gaps, (2) identifies their causes, and (3) highlights the primary issues resulting from gaps in ocean data.[6]

This analysis has thus been split into three main sections based on geographic areas of the ocean in which data gaps are especially prevalent: the Indian Ocean (*Gap 1*), Areas Beyond National Jurisdiction (ABNJs) (*Gap 2*), and the Deep Oceans (*Gap 3*). As these areas overlap, the issues and data gaps discussed in each section are not necessarily unique to those areas nor fully exhaustive.

OCEANIC DATA GAPS: CASE STUDIES OVERVIEW

GAP 1: **THE INDIAN OCEAN**

Defined as the area of ocean contained between the southern tips of Africa and Australia[7], the Indian Ocean was selected as an area of special ocean data importance for this report due to the people and communities in the area being disproportionately affected by climate change, coupled with a noted lack of resources, data, and influence on the global stage to effectively combat these changes. The Indian Ocean is also an area of importance due to its biodiversity: 30% of global coral reefs are located in the area[8], making it a priority for conservation in combating biodiversity loss and the climate crises. Finally, the issues in resource deficiency and vulnerability witnessed throughout this area are heavily rooted in the colonial history of the region[9], and the widely-recognized need for effective climate justice is a motivation for many of the recommendations from this study.

GAP 2: **AREAS BEYOND NATIONAL JURISDICTION (ABNJs)**

The second gap investigated in this report is that of Areas Beyond National Jurisdiction (ABNJs). Also referred to as the "High Seas" or "International Waters," ABNJs refer to those areas of the ocean that are outside of Exclusive Economic Zones (EEZs) and are thereby not under the jurisdiction of any one nation. EEZs (and by extension, ABNJs) were defined in the Third United Nations Convention on the Law of the Seas (UNCLOS III) which came into force in 1994. The combination of the size of ABNJs, their inaccessibility, and resulting governance challenges has led to significant and persistent data gaps across these areas.

GAP 3: **DEEP OCEANS**

Deep Oceans are defined as the areas of the ocean that are below 200m [656ft] in depth[10] – a vast proportion of the ocean. The Deep Ocean is the least observed habitat on the planet and is being increasingly exploited, with potentially devastating impacts on

[3] Annette C. Broderick, 'Grand Challenges in Marine Conservation and Sustainable Use', Frontiers in Marine Science 2 (2015).

[4] Linwood Pendleton, Karen Evans, and Martin Visbeck, 'Opinion: We Need a Global Movement to Transform Ocean Science for a Better World', Proceedings of the National Academy of Sciences 117, no. 18 (5 May 2020): 9652–55.

[5] Annie Brett et al., 'Ocean Data Need a Sea Change to Help Navigate the Warming World', Nature 582, no. 7811 (June 2020): 181–83.

[6] Arturo H. Ariño, Vishwas Chavan, and Javier Otegui, 'Best Practice Guide for Data Gap Analysis for Biodiversity Stakeholders', n.d., 41.

[7] 'Indian Ocean | History, Map, Depth, Islands, & Facts', Encyclopedia Britannica, accessed 28 March 2021, https://www.britannica.com/place/Indian-Ocean.

[8] Mohideen Wafar et al., 'State of Knowledge of Coastal and Marine Biodiversity of Indian Ocean Countries', PLOS ONE 6, no. 1 (31 January 2011): e14613.

[9] Kristina Douglass and Jago Cooper, 'Archaeology, Environmental Justice, and Climate Change on Islands of the Caribbean and Southwestern Indian Ocean', Proceedings of the National Academy of Sciences 117, no. 15 (14 April 2020): 8254–62.

[10] Lisa A. Levin et al., 'Global Observing Needs in the Deep Ocean', Frontiers in Marine Science 6 (2019).

[11] National Oceanic and Atmospheric Administration US Department of Commerce, 'How Much of the Ocean Have We Explored?', accessed 3 May 2021, https://oceanservice.noaa.gov/facts/exploration.html.

climate change mitigation efforts, further warranting interest for this analysis.[11]

INTERSECTIONAL DATA GAPS

Our analysis also identified several general ocean data gaps that intersect with the three major geographical gaps highlighted in this report, and that occur in all areas of the ocean within any analysis framework.

The first of these gaps is the *lack of baseline and historical data*. While ocean gaps are created or sustained by different factors in different regions, they are essential to groundtruth ocean monitoring and inform realistic and optimal conservation goals[12].

The second of these gaps is in *processing power for the analysis of large data sets*. The rise in remote sensing technologies has led to the production of very large datasets that require high levels of expertise and computing power to analyse and utilise effectively. This lack of resources inhibits the effectiveness of the data collecting technologies through the creation of a bottleneck. It can also lead to a further imbalance between geographic areas with higher levels of technical resources who have the means to collect, analyse and use data to inform their decisions, and those areas that do not[13]. This problem adds to the need for the transfer of technology and accompanying training as well as investment in computing resources.

A related third general gap is the *availability and useability for decision makers of existing datasets*. Ocean data that could be of use in developing regulations or strategic planning is often difficult for decision makers to access or engage with because it is hard to find, difficult to understand, or not collected in such a way as to be of easy analytical use. It is the perspective of the authors of this report that data should be findable, accessible, interoperable and reproducible (FAIR), in keeping with current best practices from data science.[14] End-user involvement in the collection of data and the creation and maintenance of databases is key to improving the accessibility and use of data.

While there are many facets to the lack of sufficient high quality ocean data and its use in decision-making, identifying and addressing their causes is critical to address if we are to ensure the responsible stewardship of the ocean and its resources for people and planet.

[12] R. H. Thurstan et al., 'Filling Historical Data Gaps to Foster Solutions in Marine Conservation', Ocean & Coastal Management, Making Marine Science Matter: Issues and Solutions from the 3rd International Marine Conservation Congress, 115 (1 October 2015): 31–40.

[13] Lynda E. Chambers et al., 'Southern Hemisphere Biodiversity and Global Change: Data Gaps and Strategies', Austral Ecology 42, no. 1 (2017): 20–30.

[14] Mark D. Wilkinson et al., 'The FAIR Guiding Principles for Scientific Data Management and Stewardship', Scientific Data 3, no. 1 (15 March 2016).

DATA GAP 1: THE INDIAN OCEAN

IMPORTANCE

Significant gaps in data and information about the Indian Ocean exist due to a lack of appropriate data collection resources, available processing power, and insufficient governance frameworks for resource management within the region. It is also important to note how the enduring legacy of colonialism within the area has influenced the current scarcity of research facilities bordering the Indian Ocean and the lack of precedent for in situ data collection, particularly in remote areas. These elements have contributed to the structures and foundations necessary for long-term oceanic data collection and management in the present day not being adequately developed.

The resulting data gaps have huge implications for the communities who live in these areas, especially as they are often some of the most vulnerable to climate change impacts and environmental degradation despite having little to no role in creating these crises. For example, communities in many Small Island Developing States (SIDS) in the Indian Ocean are already being affected by direct climate change impacts – including increased global temperatures and a rising sea level – which are causing rapid, devastating changes. Given, too, that many of these communities are reliant on surrounding ocean ecosystems and resources, it is concerning that these states rarely have the resources to collect and analyse their own data that would allow them to make informed decisions about responding to their rapidly changing environment[15].

Despite being on the front lines of the physical impacts of ongoing climate change, vulnerable communities (and SIDS especially) are often underrepresented in regional and international governance negotiations, leading to insufficient consideration being given to their political and environmental interests. In addition to these communities frequently not having a seat at the table in negotiations, they are also often side-lined in climate models due to a lack of representative data. Global Climate Models (GCMs) are relied upon worldwide for accurate climate change predictions; a lack of data in regions such as the Indian Ocean leads to a need for extrapolation, thus rendering predictions less accurate and with a much higher degree of uncertainty in these areas.[16]

Data gaps about the Indian Ocean thus result in negative consequences for local communities and ecosystems, undermine good scientific research and understanding, and threaten global efforts to preserve biodiversity and tackle climate change.

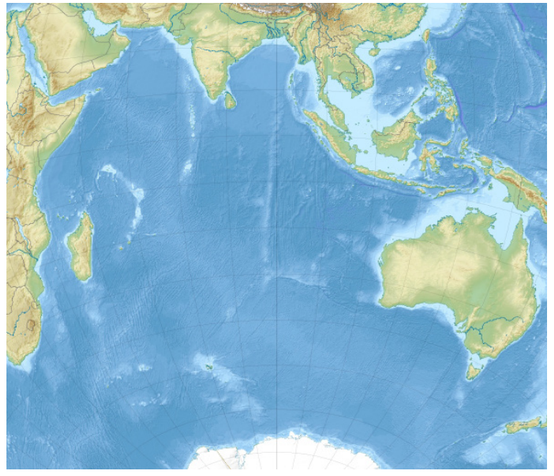


Figure 1: *Geographic relief map of the Indian Ocean (via naturalearthdata.com)*

STAKEHOLDERS

There are many important stakeholders engaged with the Indian Ocean, with the primary being the 2.5 billion people who reside along its land borders.[17] These local communities are dependent on ocean ecosystems and resources while also being highly vulnerable to the effects of climate change.

As previously noted, while the domestic scientific capacity of many places around the Indian Ocean is limited due to lack of resources, there are also a number of international scientific organisations and academic institutions active in certain areas for the purpose of studying (a) the area's complex marine ecosystems, and (b) how these are threatened by anthropogenic activities. It is widely acknowledged that the Indian Ocean is a biologically rich and interesting area of study. More and better data from this region is a priority for academics and international organisations, including the International Panel on Climate Change (IPCC), who would value an improvement in available data from the area to facilitate an increased understanding of fragile ecosystems as well as improve predictions from Atmosphere–Ocean General Circulation Models (AOGCMs).[18]

The responsibility of ensuring the resilience of local communities to climate change, in addition to preventing their members' exploitation by many industry stakeholders, falls in large part to regional and national governments. Political challenges and the previously noted

[15] 'Ocean Data Gap Puts Pacific Islands in Peril', SciDev.Net (blog), accessed 28 February 2021, https://www.scidev.net/global/news/ocean-data-gap-pacific-islands-peril/.

[16] Chambers et al., 2016

[17] Craig Jeffrey, 'Why the Indian Ocean Region Might Soon Play a Lead Role in World Affairs," The Conversation, 14 January 2019, https://theconversation.com/why-the-indian-ocean-region-might-soon-play-a-lead-role-in-world-affairs-109663

[18] Carlos Andrade, Status of Ocean Observations and Data Gaps for Response to Climate Change in CPPS Countries, 2017

general lack of slack resources means that often times many governments around the Indian Ocean region have neither the structure nor capacity, let alone information, to make well-informed management decisions or to enforce the resulting decisions and/or regulations. For example, fisheries are the dominant industry stakeholders in the region and have specific regional organisations (i.e., Regional Fisheries Management Organisations, or RFMOs) in place to regulate them. However, the fishery industry in the region ranges in size from large global, commercial fleets to small community fisheries. This diversity creates challenging dynamics for the RFMOs to regulate them and the current governance structure is inadequate for making this regulation sufficient.[19] Many communities throughout the region are also highly dependent on these fisheries for food security and livelihoods, making them especially vulnerable both to exploitation and impacts of climate change.

Filling data and governance gaps in this region is thus essential for appropriate climate justice action as well as addressing both academic and/or commercial motivations. Following best practices, those stakeholders most impacted by gaps in ocean data – and its resulting consequences for effective, just, and equal local governance – must be better represented when formulating solutions and be proactively involved when developing ongoing environmental and governance-related decision-making processes.

CAUSES

The paucity of available ocean data in the Indian Ocean today is linked to poor data and data infrastructure as well as insufficient or poor existing governance. From the data side, issues stem from the sparse distribution of research facilities and resources throughout the area. Stations used to take measurements of ocean data are few and dispersed, particularly for SIDS[20], which leads to sparse coverage of available in situ data combined with gaps in historical data. This is particularly true for remote areas and non-coastal ocean areas.[21]

These data gaps (along with poor data infrastructure for collecting and managing ocean data) have been further exacerbated by *"helicopter research."* This term is used to describe an exploitative practice whereby scientists collect and extract data for use elsewhere without seeking to engage with the local community in a meaningful, ongoing way, ignoring the importance of forming long-term local partnerships with communities and research facilities to ensure the establish the sustainability of an ongoing research program while also increasing a community's capacity to collect their own data.

This type of research practice also leaves communities without appropriate resources to manage and process data, nor create and maintain usable databases on their own.[22] Such a lack of engagement with local communities is not only highly damaging to the communities themselves (who are left without sufficient, accurate ocean data to inform decision-making) but also ignores a wealth of local knowledge that could be beneficial to scientists' understanding of the ocean, reinforcing existing gaps in data coverage and breaks in the continuity of ocean data in these areas. As is widely acknowledged by academic, historians, and policy experts, coastal communities tend to possess extensive local knowledge which can be drawn upon to fill data gaps in research and historical records. Collaboration with local communities also allows conservation efforts to be more effectively tailored to the communities that live with and depend on the threatened ecosystems, further improving the efforts' effectiveness.[23] Improved data collection and the technological resources to form sufficient data infrastructure (complemented by skills training) are both necessary for better ocean data, and therefore would improve the state of ocean conservation in the Indian Ocean.[24]

Insufficient governance infrastructures, representation, and funding in the region also cause gaps in ocean data and block effective ocean conservation. Investment by local and national governments in the Indian Ocean for training and resources to effectively collect, collate and analyse data is often of lower priority for government funding than other critical issues deemed of more immediate concern, such as health and education.[25]

However, the global community can make an important contribution to tackling this issue through meaningful support and investment in upskilling the local talent required for maintaining sustainable ocean data collection processes alongside physical improvements in locally-accessible data infrastructure. The authors of this report believe that, from a climate justice perspective, there is a strong case to be made for stakeholders based in the Global North contributing financial and knowledge resources in a substantial and meaningful way[26] towards supporting local upskilling and physical data infrastructure improvements. Such engagement would serve to (in part) fulfill a moral obligation surrounding the long-lasting impacts of colonialism, as well as help to increase available, high-quality data from this area for the global benefit of scientific understandings of the ocean, enable better environmental resource management, and support local conservation initiatives.

The intersection of these issues is best illustrated by the example of Regional Fisheries Management Organisations (RFMOs) in the Indian Ocean. As previously noted, many of the communities in these regions are dependent on fisheries for their livelihoods and food security. However, due to ongoing governance issues and data gaps, these resources are being exploited to the detriment of local communities. European Union tuna fishing activities in the Indian Ocean – with fishing fleets much larger than many of the local small-scale vessels, leading to a disproportionate exploitation of these ocean ecosystems – have been called 'neocolonial' by The Guardian.[27] Unfortunately, as there is no RFMO in which all Indian Ocean coastal states hold membership, the management of fisheries in the area remains incomplete and open to exploitation. Such gaps in governance are then compounded by the lack of data collection and processing capacity of Indian Ocean coastal states to inform and implement effective conservation targets, preventing exploitation and increasing local advocacy for the better management of their marine resources.[28]

[19] Claire van der Geest, 'Redesigning Indian Ocean Fisheries Governance for 21st Century Sustainability', Global Policy 8, no. 2 (2017): 227–36.
[20] Piotrowski, 2015
[21] Andrade, 2017
[22] Ina Tessnow-von Wysocki and Alice B. M. Vadrot, 'The Voice of Science on Marine Biodiversity Negotiations: A Systematic Literature Review', Frontiers in Marine Science 7 (2020).
[23] Alexander et al., 2019
[24] Chambers et al., 2016
[25] ibid.

[26] Sharon L. Harlan, David N. Pellow, and J. Timmons Roberts with Shannon Elizabeth Bell, William G. Holt, and Joane Nagel, 'Climate Justice and Inequality, Climate Change and Society: Sociological Perspectives, eds. Riley E. Dunlap and Robert J. Brulle, Report of the American Sociology Association's Task Force on Sociology and Global Climate Change, Oxford University Press, 2015: 127-163.
27 Karen McVeigh, 'EU Accused of 'neocolonial' plundering of tuna in Indian Ocean,' The Guardian: Environment, 5 March 2021, https://www.theguardian.com/environment/2021/mar/05/eu-accused-of-neocolonial-plundering-of-tuna-in-indian-ocean
[28] Geest, 2017

DATA GAP 2: AREAS BEYOND NATIONAL JURISDICTION

IMPORTANCE

Despite their vast size – i.e., ABNJs make up 64% of the world's oceans[29] – and the global importance of the ecosystems contained within them, ABNJs are relatively unknown within the wider public and remain understudied. Anthropogenic activities and influences within ABNJs are increasing, largely unseen and unmonitored, with the resulting negative externalities shown to threaten the health of the oceans and the benefits these areas provide (e.g., such as in the case of deep-sea mining[30]).

ABNJs contain many diverse ecosystems which are highly vulnerable to the effects of human interference and climate change. These ecosystems are already not well studied and understood due to existing data gaps. Data relating to biodiversity and ecosystems in ABNJs is especially sparse, and the increase in human interventions in these areas has only led to more uncertainty over how these ecosystems will be affected by threats including over-exploitation of natural resources, habitat degradation, and pollution.[31] In the vast and fluid marine environment of ABNJs, there is also poor understanding of ecological connectivity between areas and no sufficient measure of how protected an area is.[32] Recent developments in remote sensing technologies have improved the availability of data in ABNJs (particularly for monitoring purposes), but spatial coverage remains incomplete due to the sheer size of the area.[33] The rapid increase in the amount of raw data available has also led to an escalated need for the expertise and processing power required to analyse such data to extract meaningful results.

It is particularly critical that ocean stewards seek to fill the existing ABNJ data gap as these areas contain large numbers of both vulnerable ecosystems *and* globally shared marine resources that are highly exposed to negative anthropogenic threats, yet remain largely unregulated due to a lack of any overarching governance framework in place to manage activity in international waters.

STAKEHOLDERS

Anthropogenic activity in ABNJs is increasing due to a large (and growing) number of stakeholders competing for limited natural resources. Commercial fisheries are highly active in ABNJs[34] and harmful fishing techniques, such as trawling, are heavily employed. While fishing vessels provide some useful data relating to ABNJs through programmes including Global Fishing Watch (GFW)[35], there is much more useful data they could also be providing using resources that already exist. Analysis shows that this lack of data collection and sharing is frequently due to (a) an unwillingness from fisheries to share more data for fears of increased regulation, and (b) the lack of a governance framework that sufficiently monitors their activities while enforcing data sharing. Oil and gas extraction is another large industry operating in ABNJs that also has the potential to provide useful data for wider ocean stakeholder use but is currently not – for example, through open access environmental surveys or sensors fitted to oil rigs.[36]

Data from ABNJs is essential for academia and research purposes as researchers seek to understand ocean ecosystems, their baselines, and the effects of climate change and human interventions. Of the limited existing data collection schemes in place, some – such as the Argo[37] project – are specifically for academic research purposes. This fleet of battery-powered, robotic buoys is released throughout the oceans to float with ocean currents, all the time collecting oceanographic data from below the water's surface. Remote sensing technologies like those used for Argo are one method being employed to address some of the difficulties of the vast size and inaccessibility of ABNJs, yet also bring new problems in the form of increased needs for processing power and digital expertise.

It is worth noting that there is also the future potential for even more stakeholders to become active in ABNJs due to increased interests in innovation areas surrounding marine genetic resources, aquaculture, and geoengineering.[38] Although they do not operate directly within ABNJs, national governments are known to have commercial and societal interests in the resources and regulation of these areas (e.g., through nationally-owned industries). However, the governing bodies that provide overarching regulation throughout ABNJs are exclusively international organisations such as the United Nations Convention on the Law of the Sea (UNCLOS) and the High Seas Alliance. Governments and international governing bodies must collaborate to regulate activities and encourage data collection – as well as sharing within ABNJs – to ensure that these areas are not over-exploited beyond their self-sustaining threshold to the point of destruction, leading to devastating and potentially irreversible effects on society.

[29] 'Governance Challenges, Gaps and Management Opportunities in Areas Beyond National Jurisdiction' (Global Environment Facility, 2016), https://www.openchannels.org/literature/18142.

[30] Luc Cuyvers, Whitney Berry, Kristina M. Gjerde, Torsten Thiele, and Caroline Wilhem, 'Deep seabed mining: a rising environmental challenge' (ICUN and Gallifrey Foundation, 2018), https://portals.iucn.org/library/node/47761.

[31] Susanne Altvater, Ruth Fletcher, and Cristian Passarello, 'The Need for Marine Spatial Planning in Areas Beyond National Jurisdiction', in Maritime Spatial Planning: Past, Present, Future, ed. Jacek Zaucha and Kira Gee (Cham: Springer International Publishing, 2019), 397–415.

[32] 'Governance Of Areas Beyond National Jurisdiction - UNEP-WCMC', UNEP-WCMC's official website - Governance Of Areas Beyond National Jurisdiction, 2017, accessed 20 May 2021, https://www.unep-wcmc.org/resources-and-data/governance-of-abnj.

[33] Morgan E. Visalli et al., 'Data-Driven Approach for Highlighting Priority Areas for Protection in Marine Areas beyond National Jurisdiction', Marine Policy 122 (1 December 2020): 103927.

[34] Visalli et al., 2020

[35] More information on Global Fishing Watch's initiative is presented in Section 2.

[36] Levin et al., 2019

[37] 'Argo', Argo, accessed 20 May 2021, https://argo.ucsd.edu.

[38] Andrew Merrie et al., 'An Ocean of Surprises – Trends in Human Use, Unexpected Dynamics and Governance Challenges in Areas beyond National Jurisdiction', Global Environmental Change 27 (July 2014): 19–31.

CAUSES

The primary cause of data paucity in ABNJs is their vast size and inaccessibility. These difficulties make it challenging and costly to collect necessary data in sufficient quantities and over long periods of time in ABNJs, and have led to more resources being devoted towards coastal measurements within EEZs.

A lack of sufficient governance frameworks and data sharing partnerships have further exacerbated ABNJs' data gap. In short, the governance structures of ABNJs are insufficient to monitor the entire area they contain and protect their ecosystems effectively.[39] There is currently no global scale governing body devoted to managing environments in ABNJs and in fact, current governance frameworks in place only address one sectoral activity with no overarching rules across different sectors.[40] This is a problem considering the increase within ABNJs of a variety of anthropogenic activities shown to create negative externalities, and could result in insufficient environmental impact assessments given such assessment do not take into account the cumulative threat of multiple industries.[41]

More effective environmental impact assessments could be facilitated by (1) increased data transparency combined with (2) cross-sectoral collaboration in sharing data designed to make current and future data on ABNJs open and accessible.[42] The lack of data standardisation frameworks further contributes to data gaps, as data collected for different purposes by different stakeholders is often neither interoperable nor useful in combination with other data. The case of ABNJs provides a strong supportive argument for establishing cross-sectoral collaboration and effective data sharing partnerships that prioritize the goals of end-users. The combination of (1) data paucity in ABNJs due to their size, (2) the need for large amounts of processing power, (3) the lack of an effective environmental monitoring framework, and (4) the absence of sufficient governance structures had led to a critical ocean data gap.

Finally, the lack of area-based planning in ABNJs is another cause contributing to the data gap in these areas. The framework of Marine Protected Areas (MPAs) and area-based planning could provide an opportunity for cross-sectoral collaboration to occur and governance structures to be put in place.[43] However, no official governing body is in control of area-based management on the high seas[44], and there exists no global framework that defines criteria for selecting MPAs in ABNJs.[45] Further issues exist with MPAs in regard to conservation, as sufficient measurements of their effectiveness are non-existent and the data that *does* exist is often withheld by governments who refuse to share it. Thus, if area-based management is going to be effective in increasing ocean conservation while decreasing conflicts between stakeholders, measures of its success must be improved and standardised.[46]

[39] High Seas Alliance (HSA), 'Overview of Legal and Regulatory and Implementation Gaps in the Conservation and Sustainable Use of Biodiversity in Marine Areas beyond National Jurisdiction | InforMEA', 2014, accessed 20 May 2021, https://www.informea.org/en/literature/overview-legal-and-regulatory-and-implementation-gaps-conservation-and-sustainable-use.

[40] UNEP-WCMC Report, 2017

[41] Altvater et al., 2019

[35] Nic Bax et al., 'Open Data: Enabling Conservation and Sustainable Use of Biodiversity in Areas beyond National Jurisdiction', Current Biology 7, no. 3 (2016): R126.

[36] Altvater et al., 2019; UNEP-WCMC report, 2017

[37] Vadrot et al., 2020

[38] High Seas Alliance, 2014

[39] Natasha J. Gownaris et al., 'Gaps in Protection of Important Ocean Areas: A Spatial Meta-Analysis of Ten Global Mapping Initiatives', Frontiers in Marine Science 6 (2019).

DATA GAP 3: DEEP SEAS

IMPORTANCE

The Deep Seas – defined earlier as those areas of ocean below 200m [656ft] in depth – are another extremely large yet poorly understood area with more than 80% remaining unexplored.[47] The deep seas are essential for climate regulation: they contain over 90% of labile carbon in the earth system, making them an important resource and enabler in humanities' efforts to mitigate climate change.[48] Deep ocean ecosystems also have the potential to provide new medical and genetic resources.[49] Finally, these ecosystems are incredibly fragile: they form over thousands of years and, once destroyed, may well be unable to recover.[50]

With the rising interest in deep sea mining, cable laying, bioprospecting for medical and genetic resources, and increased waste and pollution ending up in the deep seas, anthropogenic activities with negative externalities are increasingly encroaching on these deep and valuable areas of the ocean.[51] Deep Sea ecosystems are not only vulnerable to threats from direct anthropogenic activities but also from the harsh effects of climate change, including ocean acidification. Yet, despite their sizable importance, there is a general lack of data from deep ocean areas and ecosystems. Furthermore, much of the data that *is* currently collected is done so by stakeholders whose presence in the deep seas is for the purpose of exploiting existing resources, flagging concerns over conflicts of interest.

The increasing popularity of remote sensing offers the potential for more open access and available data to be collected in the deep seas. While there remain challenges in remote sensing data collection and processing, the increasing adoption of these technologies offers expanded opportunities for more, better quality ocean data which can be leveraged for appropriate resource stewardship and conservation purposes. Technological advances for data collection, more effective data sharing regulation, and data partnerships for understanding the highly vulnerable deep sea ecosystems are all crucial elements for good research and informed management.

STAKEHOLDERS

Industry and governments are the primary stakeholders in national and international deep sea areas. The deep oceans hold vast quantities of untapped natural resources, as well as poorly understood unique and fragile ecosystems (not unlike mountain tundra). However, the primary industry in the deep seas – and the current primary source of most deep sea data – remains deep sea mining companies, supported by their governments.

More than one million square kilometres of seabed in ABNJs have been surveyed for commercial mining purposes.[52] These surveys collect baseline environmental data required by the international regulatory body (i.e., the International Seabed Authority or ISA) to license prospecting and mining in certain areas. Since these surveys are a key source of environmental data in the deep seas – and in fact, one of the only current sources – it would be extremely beneficial for their data to be shared with stakeholders and academia to remedy our ignorance surrounding these areas. However, much of the relevant data produced has not been shared to date with relevant stakeholders due to claims of such data being proprietary and/or of significant commercial value.

Next, cable laying is an industry with the potential to become more prevalent in the deep seas over the coming years. Like the oil and gas industry, cable laying, too, has the potential for data provision through both the sharing of data and environmental assessments as well as via scientific partnerships. The current state and ongoing technological development of robust oceanic sensors means that devices could be mounted to submarine cables or regional centres of oil and gas activity to provide real-time monitoring data from the sea floor.[53] This strategy could generate useful amounts of oceanographic data that would otherwise be challenging to collect.

[47] National Oceanic and Atmospheric Administration, US Department of Commerce, 'How Much of the Ocean Have We Explored?', accessed 3 May 2021, https://oceanservice.noaa.gov/facts/exploration.html.
[48] Levin et al., 2019
[49] Jesús M. Arrieta, Sophie Arnaud-Haond, and Carlos M. Duarte, 'What Lies Underneath: Conserving the Oceans' Genetic Resources,' PNAS (October 26, 2010), 107 (43): 18318-18324.
[50] Roberto Danovaro et al., 'The Deep-Sea under Global Change', Current Biology 27, no. 11 (5 June 2017): R461–65.

Academia is another key stakeholder actively engaged in contributing to the stewardship of the deep seas, with researchers offering specialised skills and expertise to improve our understanding and management of these deepest areas of the oceans. Many opportunities exist for academics to both (1) study existing environmental surveys to increase our shared knowledge about these areas, as well as (2) develop novel data collection methods (particularly for biodiversity data) so that the vulnerable ecosystems can be sufficiently understood for appropriate stewardship and protection purposes.

Finally, due to the deep seas' climate regulation capabilities, unique biodiversity, and the potential medical and genetic resources of the deep oceans, the authors believe it should go without saying that the entirety of civil society should be considered a stakeholder given the immense tangible and intangible value these ecosystems provide. Improved data on these poorly understood deep oceans is essential to prevent their destruction, and is necessary for their effective stewardship.

CAUSES

The two primary factors behind the current lack of data on the deep seas are (1) their inaccessibility, and (2) the resulting high cost of data collection. Technologies available to effectively collect data in the deep seas have only been recently developed and remain expensive. A lack of standardization and sharing of the few data that are collected has further created high barriers for users to access, compile, or use this data. In addition to being sparse, these data are primarily collected by industries with a commercial interest in the area and who do not wish to engage with the possible wider societal benefits of sharing such data.

Due to the expense of collecting data in the deep oceans, there has also been a lack of long-term funding for smaller and non-commercial data collection programs leading to the resulting data not being preserved online.[54] Thus, increased targeted or collaborative funding in both deep ocean data collection and database maintenance is needed, as well as further resource investment in the development of data standardisation and data sharing best practices for information on these valuable, yet fragile, areas.

[51] Eva Ramirez-Llodra et al., 'Man and the Last Great Wilderness: Human Impact on the Deep Sea', ed. Peter Roopnarine, PLoS ONE 6, no. 8 (1 August 2011): e22588.
[52] Visalli et al., 2020
[53] Levin et al., 2019
[54] Levin et al., 2019

SECTION 2:
CHALLENGES & OPPORTUNITIES

OVERVIEW

The recent proliferation of new marine technologies offers the potential to provide much-needed ocean data to establish effective ocean monitoring and management. Remote sensing technologies supply access and insight for researchers and the public into the far reaches of the ocean. However, though increasing volumes of ocean data are being collected, the lack of ocean data from specific areas (including the Indian Ocean, ABNJs, and the deep sea) remain significant and persistent gaps.

The scale, pace, and extent of human activity in these same, specific areas of the ocean is increasing while impacts remain largely unmonitored and unknown. However, in some cases it is precisely these activities which have the potential to fill these gaps in our knowledge and understanding. Given the remote, logistically challenging, and ungoverned nature of the seas, actors already operating in these areas have the potential to play a key role in helping fill these information and knowledge gaps. Mobilizing inter-sectoral collaboration to collect and analyse ocean data offers the potential to plug these key data gaps – and especially those in the Indian Ocean, ABNJs and the deep oceans areas identified in *Section 1*.

RESPONSIBLE DATA COLLECTION

In addition to generating and unlocking critical data to further ocean knowledge and inform sustainable management, more systematic processes for oceanic data collaboration (i.e., collection and sharing) offer new insights into the cumulative impacts of anthropogenic activities on ocean ecosystems, provide transparency on human activities on the ocean, create monitoring and research cost savings for all stakeholders, and improve the state and standardization of ocean data. In the hands of responsible and accountable stakeholders – including communities who have historically been marginalized despite their close relationship with the ocean – shared data can be a powerful tool supporting both management and advocacy for effective conservation, for the good of all.

To inform responsible stewardship and decision-making processes, data must be (1) sufficient (of good quality), (2) appropriate (of the right type and coverage), and (3) actively available to those stakeholders able to effect decisions. The flow of data from collection to usage is complex and there are multiple obstacles to this flow. Most new ocean data remains privately held and unavailable to researchers, governments, or the public. Where there are publicly available existing data, they are of vast quantities and varying qualities, requiring significant resources and expertise to unlock and analyse.

By analysing key stakeholders and selected case studies of oceanic data collection initiatives, this section posits the importance of mobilizing inter-sectoral collaboration to generate, unlock, and make available ocean data. All stakeholders have a role to play in effective ocean monitoring and stewardship. This can take place through generating new sources of data, unlocking existing datasets, and making data more freely available to those researchers and policymakers actively involved in key ocean-focused management decision-making processes.

CASE STUDIES: **OCEANIC DATA COLLECTION INITIATIVES**

INITIATIVE 1: GLOBAL FISHING WATCH (GFW)

Global Fishing Watch is an independent non-profit organisation that monitors global fishing vessel activity through satellite data. Through increased transparency of human activity at sea, Global Fishing Watch aims to provide evidence to improve ocean governance and management for ocean conservation and sustainable development.

Global Fishing Watch collects vessel location data from satellite detections of automatic identification system (AIS), a tracking system that is often mandatory for large vessels. While this data is publicly available, the datasets are large and highly complex. Global Fishing Watch uses machine learning to process these data to identify fishing activity, fishing type, vessel types, vessel movement, and vessel number. The raw outputs are made available to researchers and governments, and data visualisations are available online for members of the public and journalists alike to view (at https://globalfishingwatch.org/).

The Global Fishing Watch dataset has provided particular insight into the activity of large fishing vessels, and especially those operating in ABNJs. To expand and improve their tracking of fishing vessels, especially small vessels, Global Fishing Watch is working to partner with governments to gain access to national Vessel Monitoring Systems (VMS) tracking data.

INITIATIVE 2: INTERNATIONAL SEABED AUTHORITY

The International Seabed Authority (ISA) is an autonomous international organisation formed of 167 Member States and the European Union. I**t is mandated by the UN Convention of the Law of the Sea (UNCLOS) to organise, regulate and control all mineral-related activities in the international seabed area for the benefit of all mankind.** Its jurisdiction includes the ocean floor and subsoil beyond the limits of national sovereignty (known as 'The Area'). The ISA is required to promote and disseminate marine scientific research in the Area (*see* Article 143, paragraph 2, UNCLOS) and has committed to working to share and promote access to ocean data (*see* SD 4.3 and 4.4 of the ISA Strategic Plan 2019-2023).

In recent years there has been increasing interest in commercially mining the deep seabed, with the ISA having issued 30 exploration contracts to national agencies and private companies. Contractors are required to collect and submit resource-related, oceanographic, and biological data to the ISA to inform environmental impact assessments to fulfil the ISA's duty to ensure the protection of the marine environment from harmful effects that may arise from deep seabed-related activities. As mentioned earlier in *Section 2*, this deep sea data collected by contractors is a major source of data and knowledge on deep seabed ecosystems.

The ISA has recognised the value of this data and the opportunity of it to contribute to the advancement of deep ocean knowledge, and so in 2019 established the 'DeepData' platform to facilitate sharing historical and current non-confidential contractor data. While deep sea researchers point to not-insignificant issues in the metadata, quality, and coverage of data that are currently undermining the use of this dataset for robust analyses, DeepData represents an important ongoing effort to make available and aggregate unique deep sea data.

INITIATIVE 3: PARTICPATORY APPROACHES TO SMALL-SCALE FISHERIES MANAGEMENT IN MADAGASCAR

Small-scale fisheries represent more than 50% of the global fishing effort yet are largely unmonitored. Small-scale fishing is often conducted by small vessels working inshore, which are not required to have AIS. While some national or regional governments have tracking and monitoring systems (e.g. Vessel Monitoring System, or VMS), many governments in the Global South – where the bulk of small-scale fishing takes place – do not enforce monitoring or reporting requirements, leading to data paucity about the fishing activity and catch of the sizable small-scale fishing industry.

To fill this data gap, researchers and managers have turned to participatory and technological approaches. **Work conducted by non-profit organisation Blue Ventures in Madagascar, in collaboration with local communities, harnesses the voluntary self-reporting of fishers' catch reported on mobile phones.** The data provided by the community is analysed by Blue Ventures but retained by the community, with the resulting analyses communicated to the community to inform local management decisions. Other voluntary reporting and tracking devices to assess the impact and activity of small-scale and regional fisheries are in development and testing phases.

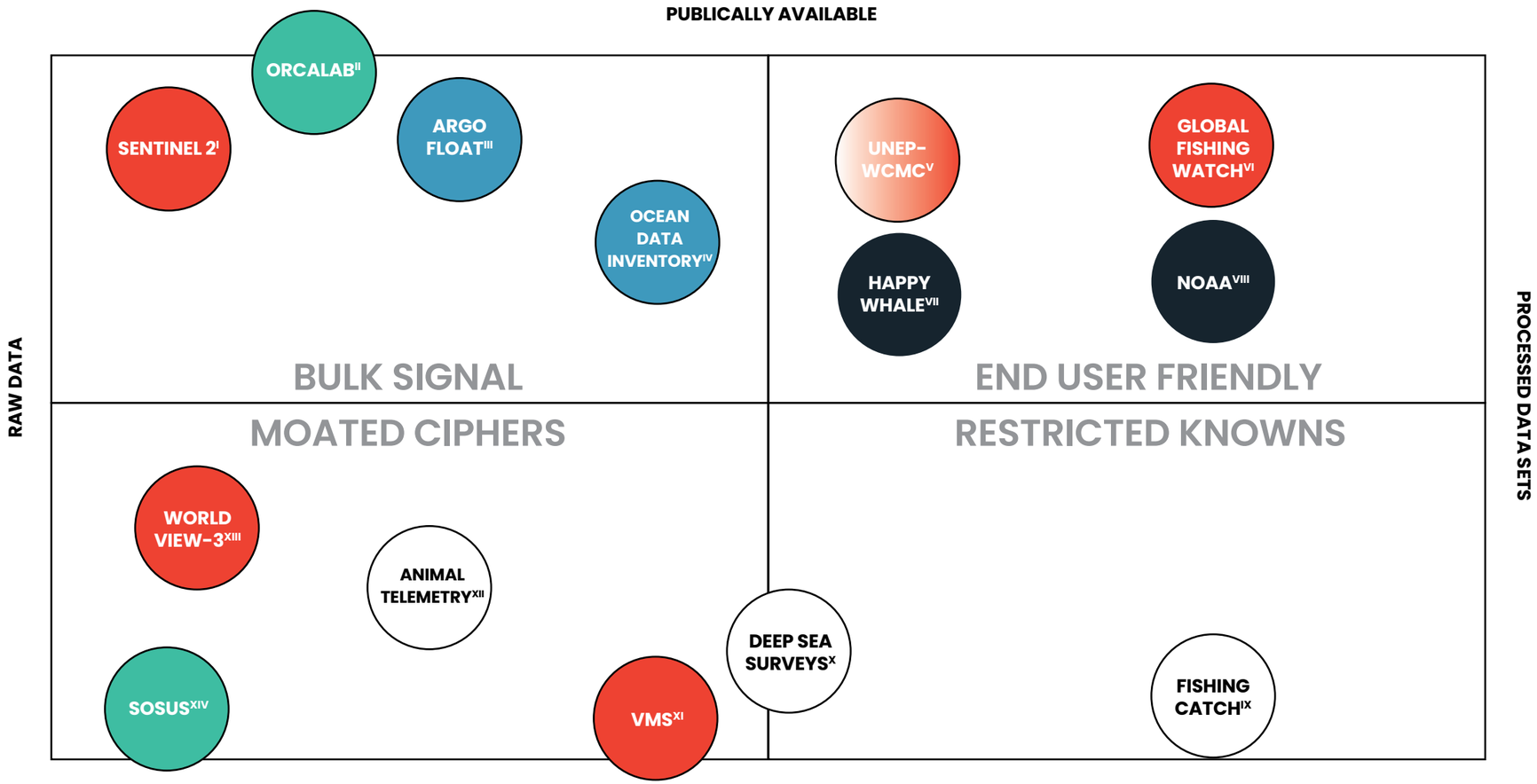
There remain challenges to the collection, quality assurance, standardisation, and aggregation of small-scale fishery data. Yet, participatory and technological approaches offer an important opportunity to collect data at a local level that will then feed into larger datasets to provide insight about the activities and impact of small-scale fisheries at a global scale. Such data also works to empower local communities through the collection of additional evidence that can be used to make better informed ocean stewardship decisions.

INITIATIVE 4: DEEP-OCEAN ENVIRONMENTAL LONG-TERM OBSERVATORY SYSTEM (DELOS)

The Deep-ocean Environmental Long-term Observatory System (DELOS) is a collaboration between British Petroleum (BP) and the University of Aberdeen that established a scientific observatory on a BP oil rig in Angola. While certainly not the first collaboration – oil and gas companies and many universities have a well-established relationship – this project is an interesting case study because BP provided a physical platform on existing infrastructure assets for researchers to deploy a scientific observatory. This partnership has provided scientists with a unique window into deep ocean oceanography and biology, and resulted in several peer-reviewed papers providing additional insight into deep sea ecosystems. The data collected are held in a database maintained by BP. While the data are not publicly available, they are available to researchers on request.

Within the scope of ongoing climate justice efforts, this collaboration is also of interest given both partners – a British company and a Scottish University – are operating this project within the national waters of Angola, a previously colonized country in the Global South. While the project has provided resources and training for Angolan government researchers, it should also be noted that the data on Angolan ocean floor bed and ecosystems is not owned by Angola.

FIGURE 2: AVAILABILITY OF SELECT OCEAN DATASETS



TYPES OF DATA AVAILABLE

- SATELLITE DATA PRODUCTS
- ACOUSTIC DATA
- OCEANOGRAPHIC DATA
- CITIZEN SCIENCE
- BIOLOGICAL DATA

DATASETS INCLUDED

- **I** Sentinel 2 – Satellite Imagery
- **II** Orcalab (NGO) Acoustic Data
- **III** Argo Float Data from the UK and Southern Ocean
- **IV** Ocean Data Inventory (Canadian Government)
- **V** UN Environment Programme-World Conservation Monitoring Centre Ocean Datasets
- **VI** Global Fishing Watch (intersectoral partnership)
- **VII** Happy Whale Citizen Science Initiative
- **VIII** Marine Debris Monitoring and Assessment Project (NOAA)
- **IX** Fishing Catch (national-level data)
- **X** Deep Sea Surveys (incl. seabed mapping)
- **XI** Vessel Monitoring System (National) Datasets
- **XII** Animal Telemetry (using animal-borne sensors)
- **XIII** Worldview-3 Satellite Data
- **XIV** SOSUS (US Military Acoustic Data)

OPPORTUNITIES TO ADDRESS DATA GAPS

The flow of ocean data from collection to decision-maker is complex and can vary, but generally follows a pathway from collection > storage > processing > usage. The flow of data can be blocked at numerous points along this journey, causing a lack of data or narrowing of available data for research and decision-making. Identifying the location and causes of these blockages is a useful exercise as it allows us to troubleshoot for how data flow can be improved. Stakeholders fulfilling different roles along the data pathway can intervene in complementary ways to facilitate and increase data flow to fill the ocean data gaps described in greater detail in *Section 1*.

IMPROVING THE OCEAN DATA PIPELINE

The authors of this report believe that the generation of new data assets assists in improving the type and quality of data fed into the pipeline in the first instance. Strategic identification of ocean data gaps combined with investment and resource support to fill those gaps is needed from relevant stakeholders. For example, improved remote sensing technologies can extend the coverage of global oceanographic data, while solar-powered vessel tracking devices attached to small vessels can provide insight into the fishing activity of the numerous small-scale fishing communities.

When data *do* exist and are aggregated and stored properly, they must be processed and analysed to be of use. While we are collecting more ocean data (especially through more remote sensing technologies), the resulting datasets are increasingly large and complex. Machine learning is considered a current best practice for the automated processing of these datasets. However, this process requires extensive expertise and computational power, restricting the pool of stakeholders who are able to clean and analyse this data to those with access to sufficient talent and computational resources.

UNLOCKING PRE-EXISTING DATASETS

Stakeholders can also assist in making more ocean data available through the data pipeline by unlocking pre-existing datasets, such as the Vessel Monitoring Systems (VMS) tracking data currently sought by GFW. This approach helps reduce exploratory data collection costs while increasing available data assets for a wider pool of interested researchers and regulators. As previously mentioned, GFW's ongoing work processing free satellite datasets to identify fishing activity and effort in the High Seas is an prime example of how skilled stakeholders can share expertise by unlocking pre-existing data to increase data transparency and accountability for pools of interested ocean stakeholders.

SHARING INFRASTRUCTURE AND/OR EXPERTISE

As illustrated by GFW, stakeholders can contribute to the generation of new data assets and the unlocking of large datasets through sharing infrastructure and/or expertise. As another example, industry in the high or deep seas have the opportunity to partner and share their physical infrastructure to enable researchers to collect data from typically inaccessible locations as was done by BP for the DELOS project (*see* Figure 1). Other companies with strong computational power or talent resources can also partner with researchers, local communities, and regulators who lack such capacities to assist in

processing large data sets. A strong example of this can be seen in Google's involvement with Global Fishing Watch, where Google partnered with non-profit organisations Oceania and SkyTruth to create "the world's first global view of commercial fishing activities."[55] Finally, academia offers collaborative possibilities through conducting analyses of available data resources and supporting the development of expertise, as seen through existing combined-purpose researcher training programs and knowledge centres like the University of Cambridge's 'AI for the Study of Environmental Risk' program.[56]

SHARING DATA

While the sharing of data itself between stakeholders can make powerful contributions to plugging ocean data gaps, it can also be the most challenging of these recommendations to implement. Some stakeholders are already engaging in data sharing practices: for example, academic researchers are increasingly making their data available online for re-use through open-access publishing. Many governments are also instituting open data initiatives to make data collected by public money open, improving transparency and encouraging the re-use of data. Other government data, such as Vessel Monitoring System (VMS) data, is more challenging to share, but has been done under specific circumstances.

On the other hand, industry stakeholders have historically demonstrated a reluctance to share data (including environmental baseline data collected for monitoring and impact assessment purposes) due to concerns over proprietary data and confidentiality. However, this same data is often extremely insightful, not to mention critical for informing wider stakeholders' understandings towards and responsible stewardship of ocean ecosystems and resources. To address industry concerns, third party organisations (including intergovernmental organisations) can provide credibility and third-party confidentiality to aid in industry-collected data sharing while still maintaining degrees of transparency and, importantly, accountability.

IMPROVING DATA ACCESSIBILITY AND USAGE

Finally, stakeholders can intervene to improve or encourage the accessibility and usability of ocean data. Through the International Oceanographic Data and Information Exchange (IODE), intergovernmental organisations like UNESCO's Intergovernmental Oceanographic Commission (IOC) can support the maintenance and longevity of important datasets by providing resources to ongoing databases like the Ocean Biodiversity Information System (OBIS). Researchers and data scientists alike can contribute to the analysis and visualisation of these datasets, transforming existing data into user-friendly analyses more relevant to management and policy issues – as well as accessible to members of the general public who are interested in ocean stewardship.

Citizens can also advocate for evidence-based management and policy-making – calling for the use of data where it exists and the creation of data where there is a data gap. In sum, intersectoral collaboration along the data flow pipeline is required to produce, unlock, share, analyse, and make available useful and relevant ocean data to relevant ocean stakeholders and stewards.

[55] Lulu Chang, 'Google is using machine learning to keep track of fishing activity worldwide,' DigitalTrends, 16 September 2016, https://www.digitaltrends.com/web/global-fishing-watch-google/

[56] Information on the programme can be found here: https://ai4er-cdt.esc.cam.ac.uk/

SECTION 3: INTERSECTORAL DATA COLLABORATION

STAKEHOLDER BENEFITS

Based on the interviews and research conducted for this report, the authors believe that significant benefits exist for all stakeholders who engage in intersectoral collaboration with respect to ocean data. As has been previously illustrated, such collaborations have been shown to improve ocean data and advance ocean knowledge and conservation, as well as increase transparency and traceability of data for participating stakeholder groups. This section will outline several advantages of intersectoral data collaboration for different types of stakeholders, including but not limited to transparency, cost-efficiency, and assisting in better resource management.

MARINE INDUSTRIES

By participating in intersectoral data collaboration, marine industries can improve the transparency and traceability of their supply chains. Supply chains are challenging to secure on the ocean, particularly in ABNJs, but doing so is important to both prove compliance with regulation and demonstrate the sustainability of operations. Crucially, when coupled with accountability, increased transparency can build the public trust required to maintain the social license that companies need to operate in the oceans and utilise global marine resources.

GOVERNMENT AND PUBLIC SECTOR

Government investment in intersectoral ocean data collaboration is likely to result in better monitoring of marine activities and resource use, as well as lowering costs associated with this monitoring. When managed appropriately, improved monitoring can support higher degrees of transparency, accountability, and enforcement surrounding stewardship decisions for the benefit of marine resources and the people who rely on them. Increased monitoring over their national waters further enables stronger government oversight over – and in some cases, the ability to limit – the activities of international actors engaging in harmful oceanic activities within a national jurisdiction.

However, it should also be noted that in countries with previously known histories of corruption, the transparency of such data is vital to ensure accountability at an international level. In general, making more and better quality data and analyses available to government decision-makers is likely to support better decision-making with respect to the long-term sustainable use of marine resources.

INTERGOVERNMENTAL ORGANISATIONS

Intergovernmental organisations can further their goals of international cooperation and coordination with respect to the collection and usage of ocean data by (1) participating in or facilitating intersectoral data collaboration, (2) contributing to more efficient and effective use of countries' marine resources, and (3) supporting systems-level sustainable development efforts necessary to ensure such data collection programmes are successful. As of 2021, the United Nations announced the launch of the UN Decade of Ocean Science for Sustainable Development[57], signaling an increased focus on and resource flows towards this space.

ACADEMIA

Academia stands to benefit greatly from intersectoral oceanic data collaboration, not least through access to bigger and better quality datasets that can be used to fill current data and knowledge gaps. Data collaboration can also improve ocean-specific data processing and analysis processes that can allow for comparison and integration of datasets to answer critical research questions. Given the central role of peer-reviewed research in creating a common knowledge base shared by all stakeholder groups, academic engagement with intersectoral ocean data collaboration provides not only benefits to engaged researchers but to the wider stewardship community as well.

CIVIL SOCIETY

Civil society, including non-governmental organisations (NGOs) and local communities, benefit through improved access to and transparency around more complex ocean data sets. These can be used to complement existing community knowledge through decreasing the scope of unknown risks, helping communities and NGOs to make well-informed decisions that support the sustainable management of national and global ocean resources. Data collaboration can also improve the transparency of marine activities and impacts. At a fundamental level, data is knowledge. When underpinned by appropriate analytical support, it becomes an important empowerment tool that people can use to advocate for stakeholder accountability and better ocean management politices in their role as stewards of their communities and the planet.

[57] *Information on the programme can be found here: https://www.oceandecade.org/*

BARRIERS TO COLLABORATION

Intersectoral data collaboration has the potential to advance the state of ocean data while providing benefits to engaged stakeholders. However, significant potential barriers do exist. Some of those identified in this section are common to other data pathways and ecosystems, while other challenges are unique to the vast and harsh ocean environment and complex (and, largely ungoverned) web of ocean actors.

ESTABLISHED DATA SHARING CULTURE

First, the general lack of an established culture of data sharing poses a major primary obstacle to intersectoral data collaboration. Regular data sharing and related collaboration remain uncommon in both academia or industry. In academia, raw data is rarely made open or public. This lack of data sharing has been well-documented in the literature, which points to a variety of reasons that may motivate such restrictions ranging from author concerns about being the first to publish analyses of a particular dataset, to conditions from funders, to a lack of time or funding to publish datasets.[58] In industry, concerns about retaining a competitive advantage via proprietary data further reinforces a culture of secrecy. Within the fishing industry in particular, concerns surrounding the consequences of transparency and the inability to secure the integrity and sustainability of supply chains are common. Other industries, such as deep sea mining, have historically also been opaque and have previously faced political controversy, perhaps further contributing to a willingful lack of transparency and reticence to engage in data sharing or data collaboration.

DATA LICENSING AND OWNERSHIP

Questions surrounding data licensing and ownership pose further challenges to data sharing and collaboration. There are many reasons for data to be restricted in its circulation, including being proprietary (e.g., that are linked to information on mineral abundance in the deep ocean), sensitive (e.g., animal telemetry data that might reveal the location of endangered sought-after species), or regulated by industry agreements (e.g., fishing catch data). These can lead to data (1) not being available to other stakeholders important in the ocean stewardship process, including governments or regulators, researchers, and the public, and/or (2) being aggregated to the point of being useless (e.g., again, fishing catch data). Even data seemingly unrelated to conservation could be helpful, for example mineral-related data informing habitat identification and modelling of deep seabed ecosystems. The overall complexity and general stakeholder lack of understanding regarding data licensing and regulations make these issues challenging to navigate and overcome.

COLLECTION, MANAGEMENT, AND DATASET USE

From a technical perspective, collecting, managing and using the datasets themselves can also present significant obstacles to intersectoral data collaboration. Datasets can be large and complex, leading to technical challenges in their handling and storage. Without proper metadata, standardisation and quality assurance, data will fail to be FAIR (i.e., findable, accessible, interoperable and reusable). Data must also be appropriate if it is to be of use. As proponents of data science best practices highlight, blind data collection without end-user input *will not* produce the data required to answer a particular question. This raises further hurdles for data sharing and collaboration as different stakeholders, with disparate questions and goals in mind, will collect and handle data in different ways.

LACK OF RESOURCES AND EXPERTISE FOR BACK-END MAINTENANCE

One of the most significant barriers to data sharing and collaboration remains the lack of resources and expertise required for data processing, storage and usage. All along the data pathway after the generation of data assets, significant resources and expertise are required to maintain the flow of data: from database creation and maintenance to data quality assurance and maintenance, data processing, data sharing, and finally the analysis to make data and information available for decision-makers and civil society. The substantial and long-term funding required for this back-end maintenance can be low priority for governments and private companies. While good examples exist of intergovernmental organisations picking up this burden, recognizing across all stakeholder groups the importance of and need for resource and expertise supporting back-end maintenance – and taking concrete actions to address this deficit – is crucial to sustainably filling existing gaps in ocean data.

POOR OCEAN GOVERNANCE PRACTICES

The lack of governance, or poor governance, that is common in many areas across the world's oceans creates an additional barrier to meaningful intersectoral data collaboration. By leaving open regulatory gaps for government and industry actors operating within these areas, insufficient ocean governance can support a system absence of data collection – and *certainly* does not promote data sharing. For example, there is no regulator of fishing activity in ABNJs. Where regional fisheries management organisations (RFMOs) do exist, they are often controlled by wealthier countries and can be poorly implemented (e.g., as seen in the Indian Ocean in *Section 1*). In other cases, the regulator exists but can fail to effectively implement its mandate. In the case of the International Seabed Authority, many scientists and environmental conservationists have voiced their belief that the body fails to regulate industry in a transparent manner. Strong and fair regulations are required to ensure government and industry regularly collect good quality data and make it available, if intersectoral data collaboration is to be made possible let alone successful.

ETHICAL CONCERNS

Finally, ethical concerns may hamper efforts at intersectoral data collaboration. Concerns exist about potential conflicts of interest for regulators, governments, or industry actors who are collecting ocean data that will be used to judge their impacts. A significant challenge for industry is ensuring the trust of the public to retain its social license to operate in the ocean and (sustainably) exploit global marine resources. On the other hand, while industry may wish to employ academics and/or researchers to conduct research on their behalf, there is often reticence among many researchers to be involved with private companies operating within this space, usually based on a variety of ethical concerns (e.g., research impartiality; proven track records of negative environmental, social, or economic externalities or practices, etc.)

[58] *Willem G. van Panhuis, Proma Paul, Claudia Emerson, John Grefenstette, Richard Wilder, Abraham J Herbst, David Heymann, and Donald S Burke, 'A systematic review of barriers to data sharing in public health,' BMC Public Health 14, 1144 (2014).*

ENABLERS TO COLLABORATION

Although obstacles to intersectoral data collaboration abound, so too do opportunities. Many of the factors encouraging cooperation between stakeholders with respect to ocean data are more general societal shifts, such as the emphasis on evidence-informed decision-making and the growing recognition of the benefits of open data for science and knowledge. However, there are also several unique opportunities that arise specifically from the remote, vast, relatively unknown nature of the ocean and the complex web of stakeholders involved.

DEVELOPMENTS IN REMOTE SENSING TECHNOLOGIES

Developments in remote sensing technologies have led to ocean data being collected at an unprecedented scale. These technologies are increasingly enabling human access to new locations and collecting more data over a greater duration of time. Although there remain challenges in the resources and expertise available to process the increasingly large datasets being collected by these remote sensing technologies, significant opportunities exist in advancements in the automation of the processing of data (e.g., via machine learning approaches and technologies).

RECOGNISED NEED FOR PARTNERSHIPS

As ocean data is especially limited as compared to other environments, sharing data, expertise, resources and technologies to improve the state of ocean knowledge is more frequently being recognised across sectors. Particularly with the increase in big data and accompanying need for appropriate data processing, aggregation and storage, and management, along with the potentially powerful but complex technologies to facilitate this (including machine learning), there is a recognition of the limits in expertise and capacity of one organisation. Data collaborations are already happening (with Global Fishing Watch's partnership with governments and industry being one example), and collaboration between actors and sectors to share capacity, data and skills is likely to continue. These collaborations are vital to improving the state of ocean data: there is evidence that collaboration between diverse actors improves science and knowledge, as well as strengthens policy development.[59] For ocean data, multiple sources and users of data reinforces the importance of quality assurance, standardisation, and end-user input.

[59] Andreas Riege and Nicholas Lindsay, 'Knowledge management in the public sector: stakeholder partnerships in the public policy development,' Journal of Knowledge Management, 10(3), 24-39.

UNIQUE OCEAN DATA OPPORTUNITIES

Many have recognised a general societal shift towards appreciating the benefits of open data. While there are advantages and opportunities common across many disciplines including improving data and knowledge, rewards in academia for primary data publishing, knowledge generated through public money being made available to the public, and fostering social license to operate and trust through transparency, there are also several opportunities unique to open data in the ocean environment. For governments, open data can improve monitoring and management of remote national seas, including contributing to identifying and preventing illegal activity and improving the management of marine resources. Especially by relying on remote sensing technologies, data collaboration could lead to huge cost savings. A main challenge for industry at sea is to secure supply chains and provide transparency increasingly being required for compliance and public trust. Opportunities through data collaboration and emerging technologies (such as blockchain) provide industry with the ability to ensure traceable and sustainable supply chains – a more frequent demand from customers. For communities who rely directly on marine resources and for all those who depend on the oceans for their vital ecosystem services, data collaboration between stakeholders is vital to providing the information required to protect and sustainably manage the planet's oceans.

VALUING SMALLER, CLOSER NETWORKS

Despite the enormity of the oceans, many communities of stakeholders engaged in this space are small which encourages and promotes close networking and collaboration. For example, deep sea science is a smaller field. The resulting social connections have facilitated collaboration between academia, government, and industry. There are some well-established relationships between science and industry as well, especially in the oil and gas industry. These direct science-industry relationships, while not without risks for either side, can produce good quality novel data and relevant research.

CIVIL SOCIETY PARTICIPATION

Finally, community participation is being increasingly recognised as having an important role in data-gathering and research, especially in coastal ocean environments. Citizens can provide unique and helpful opportunities to collect data, providing local knowledge and perspective. Communities can benefit from training and resources through well-designed and implemented collaborative research programs. In turn, their heightened engagement with science and data often leads to better management outcomes, benefiting the local community and world's oceans.

SECTION 4:
STAKEHOLDER RECOMMENDATIONS

Based on the analyses presented in this report, we have identified the following key recommendations by stakeholder group. These recommendations are designed to encourage intersectoral data collaboration in pursuit of better ocean data, leading to more responsible and effective ocean stewardship.

I. GOVERNMENTS AND PUBLIC SECTOR

SUPPORT FOR AND INVESTMENT IN FAIR OCEAN DATA PRODUCTION

Governments occupy a key role in facilitating the creation and sharing of findable, accessible, interoperable, and reusable (FAIR) ocean data as both a regulator and a producer. According to best practices drawn from both data science and the principles of climate justice, the ocean data that governments and public sector stakeholders collect and produce must be FAIR. Data collected as the result of government funding must also be made available according to FAIR data principles. Here, open access requirements may be attached to researchers' grants to help increase the availability of the resulting primary data.

STRENGTHENING DATA INFRASTRUCTURE

To support this commitment, significant long-term support and investments must be made in the data infrastructure necessary to securely store and host data, including in creating, maintaining, and updating data repositories and open data platforms. Governments should focus on making data and ocean information available to communities – especially those most affected by ocean management decisions and those most vulnerable to oceanic impacts of climate change. Meaningful consultation and involvement of these communities in decision-making processes involving this data must also follow. It is worth noting that these recommendations will also improve the state of ocean data available to government's own decision-makers and policymakers. As expected in other public policy areas, obligations must exist for government to seek and use the best available information for ocean-related management decisions and policymaking.

REGULAR REVIEW OF DATA REGULATIONS

As a regulator, governments can encourage the creation and sharing of FAIR data between government departments, between industry and government, and between sectors. To do so responsibly, governments must proactively review and update government and industry sharing regulations with the aim of providing greater transparency for all involved stakeholders, including to the government itself and to the public. Considering the massive shifts in technology and data infrastructure and culture in recent years, data regulations can quickly become outdated. Instituting regular review processes will also encourage the updating and improvement of data and metadata standards to further bring them in line with FAIR data principles. The authors recommend that reviewing and making open-access datasets collected by marine industries operating in national seas be a top priority, with strategies developed for the identification and potential sharing of further datasets useful to inform government management decisions. Finally, we recommend that Government develop stronger regulations and penalties for the misuse of data to discourage its abuse or exploitation and to lay a foundation for further collaborations between sectors (e.g., between industry and academia).

II. INTERGOVERNMENTAL ORGANIZATIONS

FACILITATING EQUITABLE INTERNATIONAL COOPERATION
In facilitating coordination and cooperation between countries and through regulating international waters, intergovernmental organisations have the potential to create a large impact on developing and making available ocean data for improved stewardship. Given the vast and fluid nature of the marine environment, international cooperation is especially crucial for the good management of ocean ecosystems and resources. The authors believe that intergovernmental organisations must encourage more and better data and monitoring within national waters; better regulation of national industries in international waters; more data cooperation and collaboration between countries; and advocate for both improved ocean data and information and a stronger voice in decision-making processes for vulnerable and under-represented countries (such as those belonging to SIDS).

FACILITATING DATA SHARING VIA DATABASES AND MANAGEMENT BODIES
Intergovernmental organisations can further play a crucial role in facilitating data sharing between countries and between sectors. Intergovernmental organisations have a proven track record of long-term investment and maintenance of databases (for example, the IOC-UNESCO's OBIS database). Intergovernmental organisations can also support data sharing by acting as, or creating, third party scientific or data management bodies. This is a significant opportunity to set high and consistent data and metadata standards, improve the management and storage of ocean data, facilitate data sharing (potentially through the aggregation and anonymization of proprietary or sensitive data), prevent conflict of interest in the creation and analysis of data, allay ethical concerns that may prevent civil society or academic involvement, and ultimately improve the state and availability of ocean data to inform good management of global shared marine resources.

III. INDUSTRY

CREATION AND MAINTENANCE OF LONGITUDINAL OCEAN DATABASES
Industry has the exciting potential to play an important role in supporting the creation of FAIR data assets as well as facilitating the sharing of ocean data between companies and other key stakeholders necessary for responsible ocean stewardship. Rather than merely engaging with short-term data collection, the authors believe that companies should create and maintain longitudinal databases to store collected ocean data. While some industry stakeholders may already engage in this practice, the authors believe that it is in the best interests of all stakeholders involved in ocean stewardship if this were to become an industry best practice.

Maintaining such databases is also likely to have multiple additional long-term benefits for industry stakeholders, including but not limited to: (1) ensuring robust activity records to maintain appropriate legal accountability in the coming years, given the increased likelihood of disputes over ocean practices based on rising trends in activity across ABNJs and the deep sea, (2) assisting in the creation of more accurate risk assesments in response to escalating pressures from climate change-related extreme weather events, (3) creating opportunities for attracting young talent interested in supporting the creation and maintenance of these databases, and (4) maintaining a rich data resource that can be used to identify new and potentially valuable medical and genetic resources for further product development.

PROACTIVE DATA TRANSPARENCY AS A STRATEGIC DECISION
Whenever possible, those data should also be made available to government, researchers, and the public, either freely or in response an established and simple procedure to request information. Industry can engage in non-private sector data collaborations and partnerships directly in a variety of ways – for example, through providing access to industry physical infrastructure (as in the case of DELOS), lending computational power or expertise to process data (as in the case of GFW), or through direct data sharing. Instead of direct data collaboration, companies might also choose to use a credible third party who can facilitate the sharing of industry data through aggregating and anonymizing data in order to make it available to researchers or decision-makers. Choosing to proactively engage in increasing the transparency of available data should be seen as a strategic decision in support of the company's mission, and incorporated into operations as such.

IV. ACADEMIA

OPEN DATA AS A BEST PRACTICE
In general, data sharing needs to be encouraged and promoted as best practice across academia. The authors of this report believe that scientists, in particular, should be rewarded for publishing their primary data. While this practice is becoming more common with the rise of 'data papers' that give scientists (who publish their data through a data paper) the opportunity for recognition and an increase in citations, we see the potential for other incentives to also be established. These incentives could range from financial rewards to crediting put in place by large databases to encourage academics to contribute data to further, to preferential government support when conducting research requiring permit access.

FURTHER DEVELOPMENT OF OCEAN DATA AND METADATA STANDARDS
As well as setting best practices for data sharing and ensuring the production, teaching, and encouragement of FAIR data, the academic community must continue to develop further standards for ocean data and metadata to make such data accessible to a wider body of users and stakeholders. There is significant space for academics to further investigate potential data sharing partnerships between academia and industry, as well as different ways in which such collaborations could productively take place.

While the ethical boundaries of these collaborations are already an ongoing topic of debate, the authors believe that further work needs to be done in developing guidelines towards (a) the ethics of collaborating with industries that have a proven track record of negative environmental, social, or economic externalities or practices, as well as (b) methods for how collaboration concerns could be navigated to protect the integrity and use of the resulting research as well as the integrity of the researcher. Depending on the results of such ethical guidelines, academic institutions might consider engaging with third parties (e.g., intergovernmental organizations) in the creation of databases whereby academic and industry partners might pool anonymized ocean data while maintaining records of access.

ENDING HELICOPTER RESEARCH
Finally, academia has a responsibility to share and distribute knowledge and related resources within communities where research is being conducted. Starting from initial research design, researchers need to build in engagement with local communities and research facilities through proactive collaborations, ensuring that research benefits are reaped both by researchers as well as those affected by it. Some examples of lasting collaborations could be through shared authorship, accreditation, or shared ownership of the resulting ocean data. Ocean knowledge produced and used in the research should also be shared with the community from which it is sourced, offering community stakeholders additional data to further inform their local decision-making processes. Ethical research practices that involve communities not only empower local stakeholders and give them ownership over their own or local data, but also both normalize such practices and, more broadly, improve the quality of field-based research internationally.

V. NGOs AND CIVIL SOCIETY

ENCOURAGING CITIZEN SCIENCE INITATIVES
Civil society has the ability to contribute to ocean data in multiple ways. Through citizen science initiatives (such as the 'happy whale' database at <https://happywhale.com/>, which allows whale watchers to upload locations and images of whale sightings, or participation in self-reporting of fishing activities through phone apps), members of the public can personally contribute to ocean data collection. Engaging in citizen science initiatives through data collection and research is a crucial opportunity for people and communities to engage in the creation of ocean data, as well as address unequal concentrations of power around which stakeholders can 'claim' ocean knowledge.

EMPOWERING LOCAL COMMUNITIES VIA DATA COLLECTION AND EDUCATION
The work of NGOs such as Blue Ventures is a prime example of empowering local communities through data collection and education. In particular, their community-based Fisheries Monitoring group on Atauro Island (Timor-Leste) has (1) provided valuable ocean information to local communities to make decisions, and (2) empowered local women via facilitating data collection training, addressing existing gender inequalities by making these women valuable, key members of related decision-making processes. Putting data, knowledge, and decision-making in the hands of local people and communities through these types of initiatives and collaborations is a potentially enormous opportunity to improve the state of ocean data, and a crucial foundational step towards achieving broader sustainable development objectives within an ocean justice framework.

DEMANDING GREATER TRANSPARENCY AND ACCOUNTABILITY
In short, when appropriately supported, civil society can be a powerful force for holding governments and industries to account where there is otherwise a lack of transparency or accountability. It is the opinion of the authors that the public *must* demand greater transparency and accountability over human activities in the ocean, as well as the use of globally shared ocean resources. Civil society must call for high standards in ocean conservation and ethical data practices, including providing FAIR data, on which to base evidence-informed sustainable management. Raising awareness of the importance of ocean data for conservation through activism and education is key to bringing these issues to the forefront of public conversations if we are to drive change in all sectors of society, and foster better ocean data for better stewardship decision-making.

CONCLUSION
& SUMMARY

The vastness and complexity of the ocean environment, ocean data, and ocean stakeholders means that collaboration is crucial to generating and making available useful ocean information. Research scientists, government decision-makers, citizens, and industry practitioners can all assist in the effort to improve the state of ocean data. Remote sensing technologies, improved processing of big datasets through approaches like machine learning, increasing acknowledgement of the importance of open data and evidence-informed decision-making, and a recognition of the importance of engaging and empowering local communities (complemented by improved technologies to assist citizens' participation) are all key opportunities to promote intersectoral collaboration to generate and unlock ocean data. While not without significant challenges, improved ocean data is necessary to support good management of ocean ecosystems and resources and can even provide specific benefits to individual stakeholders.

This report has aimed to motivate urgent action towards improving ocean data by highlight select crucial gaps in ocean data, identifying intersectoral collaboration as a key approach in plugging those gaps, and outlining concrete steps for different stakeholders may contribute to improved ocean data. As should be clear from this report, a step change is required in how stakeholders (and particularly, many actors in the private sector) think about and engage with open data and data collaboration. Such a transformation is possible. This report identified several case studies that give cause for optimism and yield learnings for future data collaboration.

In short, action from all sectors is required to generate, unlock, and make available the ocean data required to effectively conserve and steward the ocean – not only for the benefit of all people, but for the planet as a whole.

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