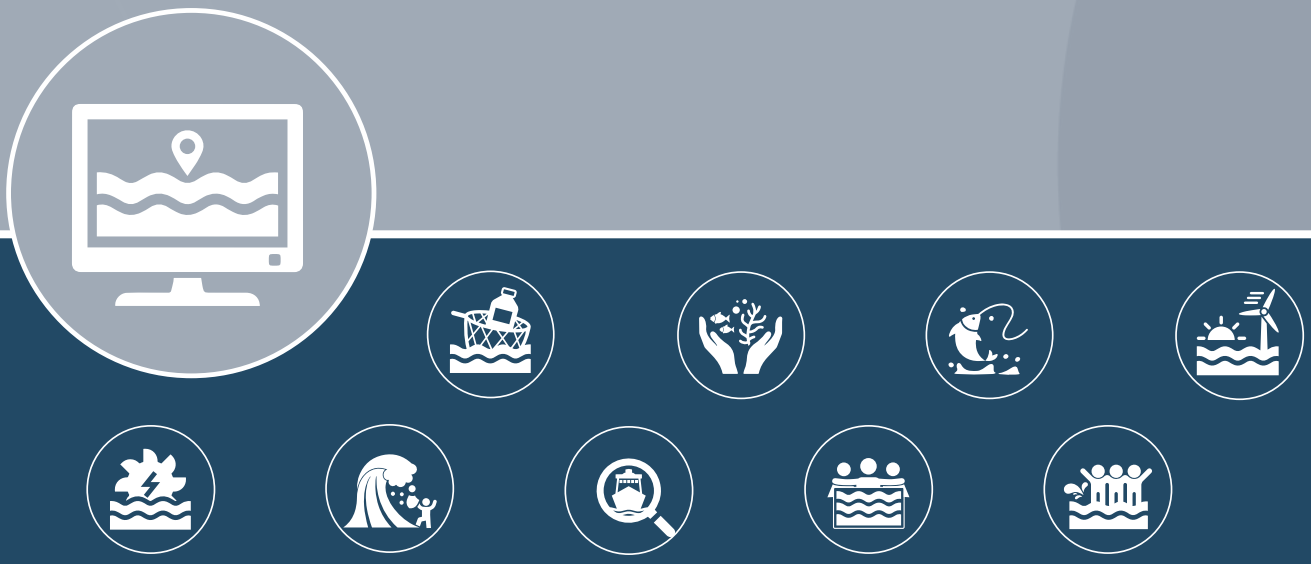
Ocean Decade

Vision 2030

White Papers

Challenge 8:

Create a digital representation of the ocean



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for Sustainable Development
(2021-2030)

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Ocean Decade Vision 2030 White Papers

Challenge 8: Create a digital representation of the ocean

Through multi-stakeholder collaboration, develop a comprehensive digital representation of the ocean, including a dynamic ocean map, which provides free and open access for exploring, discovering and visualizing past, current and future ocean conditions in a manner relevant to diverse stakeholders.

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Special thanks are extended to the Decade Data Coordination Group (DCG), whose leadership and vision for a unified data strategy have been instrumental in shaping the foundational elements of this challenge. Their commitment to fostering data sharing, integration, and accessibility across the Ocean Decade's initiatives has paved the way for this strategic ambition setting exercise.

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Finally, we thank the thematic and regional working groups, and the broader Ocean Decade community for their feedback and input as well as their ongoing support and engagement. This White Paper stands as a testament to the collaborative spirit that defines the Ocean Decade, and it is only through continued partnership and collective action that we will achieve our ambitious goal of revolutionizing the way we generate, manage and share science-based ocean knowledge.

Contents

Acronyms

AI	Artificial Intelligence
DCG	Data Coordination Group
DCO	Decade Coordination Office
DCU	Decade Coordination Unit
DDAS	Data Discovery and Access Service
DITTO	Ocean Decade Programme called Digital Twins of the Ocean
DSIG	Data Strategy Implementation Group
ECOP	Early Career Ocean Professional
EOVs	Essential Ocean Variables
FAO	Food and Agriculture Organization of the United Nations
GOOS	Global Ocean Observation System
ICAN	International Coastal Atlas Network
IOC	Intergovernmental Oceanographic Commission
IODE	International Oceanographic Data and Information Exchange
IP	Implementation Plan
LDC	Least Developed Countries
MSP	Marine Spatial Planning
SIDS	Small Island Developing States
SSFA	Small-scale fisheries and aquaculture
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization

1. EXECUTIVE SUMMARY

1.1. Introduction and Scope of the White Papers

This White Paper has been prepared as part of the Vision 2030 process being undertaken in the framework of the UN Decade of Ocean Science for Sustainable Development. The Vision 2030 process aims to achieve a common and tangible measure of success for each of the ten Ocean Decade Challenges by 2030. From a starting point of existing initiatives underway in the Ocean Decade and beyond, and through a lens of priority user needs, the process determines priority datasets, critical gaps in science and knowledge, and needs in capacity development, infrastructure and technology required for each Challenge to ensure that it can be fulfilled by the end of the Ocean Decade in 2030.

The results of the process will contribute to the scoping of future Decade Actions, identification of resource mobilization priorities, and ensuring the ongoing relevance of the Challenges over time. The process identifies achievable recommendations that can be implemented in the context of the Decade, or more broadly before 2030 to achieve the identified strategic ambition and indicators that will be used to measure progress.

This White Paper is one of a series of ten White Papers all of which have been authored by an expert Working Group. Accompanied by an Outcomes Report authored by the Decade Coordination Unit (DCU), this White Paper was discussed at the 2024 Ocean Decade Conference before being finalized and published.

1.2. Overview of the Ocean Decade Challenge

Ocean Decade Challenge 8 of the United Nations Decade of Ocean Science for Sustainable Development 2021-2030 (the 'Ocean Decade') seeks to create an adaptive and dynamic digital representation of the ocean to make the ocean accessible to a broader community, to enhance decision-making and to support sustainable ocean management.

While creating a comprehensive digital representation of the ocean is the ultimate objective of Decade Challenge 8, the focus in this White Paper is on delivering concrete outcomes and the transformational change needed to create the enabling environment and initial digital content, by 2030, that will allow us to fully deliver on the ambitions of Challenge 8 on the longer term.

An Implementation Plan (IP) for the Ocean Decade's Data and Information Strategy is currently under development by the Data Strategy Implementation Group (DSIG). This IP will outline how data systems participating in the Ocean Decade can co-create a distributed, robust, and collaborative 'digital ecosystem' that leverages open, scalable, easily implementable, and responsive technologies and management solutions. An interoperable, distributed data and information sharing system must be both deployed and maintained to allow the realization of Challenge 8, addressing specific challenges such as data interoperability, accessibility, and inclusivity.

Additionally, potential issues related to data privacy, cybersecurity, and equitable access to technological infrastructure should be addressed to ensure the comprehensive development of the strategic ambition.

In developing the Strategic Ambition for Challenge 8, we consider the data and information needs and priorities identified by the other Decade Challenges and their working groups, as our primary users (and contributors), representing as they do the key sustainability challenges for the Decade, and encompassing all relevant stakeholders.

Guided by the Decade's ambition to 'leave no one behind' we recognize that this challenge must deliver outputs that are relevant and useful for the global ocean science community, and in fact by extension the widest possible range of users and stakeholders, including the eight billion people on this planet, who should be able to access and use what is delivered by the Decade in ways adapted to their needs and capacities, if so desired.

1.3. Strategic Ambition for Challenge 8: key findings and recommendations

By 2030, the Strategic Ambition for Ocean Decade Challenge 8 is to have in place the enabling environment for the creation of and access to an increasing number of digital representations and twin applications of the ocean as well as the underpinning data and information needed to develop them, delivering at minimum 10 societally relevant[1] global base-layers accessible via a global online Digital Atlas, complemented by a minimum of 10 local use cases (prioritizing SIDS and LDCs) to address challenges in using and contributing to the Decade's distributed digital ecosystem and to demonstrate and stress test its relevance, effectiveness and inclusiveness.

In delivering this Strategic Ambition **we identify the need for the following key tools and services** to be developed and in place by 2030:

i) A federated global **Ocean Data Discovery and Access Service (DDAS)** with a map viewer providing access to multi-disciplinary data, data products and information on the past and current state and use of the ocean, accompanied by an Ocean Data Help Desk and distributed Data Ingestion service;

ii) A global **Technical and Organizational Structure for Ocean Forecasting**, promoting harmonized methods, data standards, shared architectures, and tools to foster ocean prediction worldwide, leveraging the coming innovations derived from digital twins of the ocean.

iii) A reference implementation for a global **Digital Atlas of the Ocean** (henceforth Digital Atlas), providing access to a minimum of 10 (or more) global bases layers and 10 (or more) local applications demonstrating its utility;

iv) A series of **platforms, mechanisms and tools actively used to store, share and exchange ocean information and knowledge** beyond data and data products;

v) **Enhanced capacity development and training resources and facilities** tailored to user-needs, which are actively promoted and used to radically improve digital literacy across and beyond the Decade Actions.

We also recognize the **need to put in place a transparent process for requesting, co-designing/developing, and sharing digital products and services** for use by all **and for the selection and validation of priority base layers and local case studies** for ingestion in the Digital Atlas. **Guiding principles** should underpin the **co-design and co-development process** of global base layers and local case studies. These guiding principles and processes would serve as a reference and demonstration of how the general process of base layer development can proceed by any interested party in line with the philosophy of the Decade.

In particular, we call for:

- The **Decade DSIG** to identify how Decade partners can orient their digital systems to fulfil the Decade's Data and Information Strategy, as well as the strategic ambition of this white paper towards a fully functional federated global **Ocean** DDAS by 2030, inviting the **Ocean Data 2030 Programme** to coordinate implementation of the recommendations across Decade Actions.
- The DDAS should be supported by a permanent **Data Help Desk** and distributed **Data Ingestion service**, the blueprints and trialling of which should be co-designed and driven by the **DCO-Ocean Data Sharing and the network of**

[1] Meaning relevant to achieving the Sustainable Development Goals

UNESCO-IOC's project office for IODE (International Oceanographic Data and Information Exchange) together with the Decade Implementing Partners and experts.

- The **OceanPrediction DCC** to work together with its group of regional/technical experts and all relevant Decade Actions to spearhead a transformative effort towards a global **Technical and Organizational Structure for Ocean Forecasting.**
- The **International Coastal Atlas Network (ICAN)** and communities of practice on digital coastal and marine atlases to further elaborate and define the functionality of the envisaged global **Digital Atlas of the Ocean**, cost it, and recommend a new Decade Programme to develop it, exploring also existing infrastructures developed by the private sector[2] that could be adapted.
- The **Decade Capacity Building Facility, the Ocean Teacher Global Academy and network of experts of IODE, Global Ocean Observation System (GOOS)** as well as other UN Entities and Decade Actions contributing in particular to Challenge 9 (Skills, knowledge & technology for all): to assess the needs and provide **capacity building resources** to increase the data literacy of the ocean community to ensure meaningful contributions to the Decade's digital ecosystem.
- **IODE** to foster and promote the use of **platforms, mechanisms and tools actively used to store, share, and exchange ocean information and knowledge** beyond data and data products, and inclusive of traditional and local knowledge in alignment with the Data and Information Strategy Implementation Plan.
- The **DCU** to maintain an independent **Expert Group (e.g. Decade Data Coordination Group)** beyond the delivery of this White Paper to assist with: (i) ensuring a representative and inclusive community process for the identification and selection of priority base-layers and local case studies for ingestion into the global Digital Atlas; (ii) coordinating the co-design and co-development process of these layers and case studies, ensuring alignment with the strategies and values of the Decade and their ingestion into the DDAS and Atlas; and (iii) overseeing the progress made overall towards achieving the ambition targets of Challenge 8, using the set milestones and KPIs (see Section 4 Milestones and Indicators).

Collectively these actors would work to **promote recommended practices, data standards, shared architectures, and tools to foster ocean data sharing, application, and ocean prediction worldwide**, leveraging the coming innovations derived from, e.g., artificial intelligence (AI) and digital twinning.

We highly recommend that any approach to meeting Challenge 8 should include concrete, clear, quantifiable, and effective measures to broaden **digital representation of under-represented data sources and types**. Where the lands, rights, or interests of Indigenous Peoples are involved, clear implementations of the CARE principles should be present, having been co-developed with indigenous communities from the earliest phase possible.

The above **recommendations** and requests are not the only needed to achieve Decade

[2] Reference was made to a number of major companies who are particularly active in this domain, including Google, Microsoft and ESRI with Google Earth, Microsoft planetary computers and ESRI's Living Atlas of the World. https://www.techforwildlife.com/blog/2022/10/10/google-earth-engine-vs-the-microsoft-planetary-computer, https://wildlabs.net/discussion/google-earth-engine-vs-microsofts-planetary-computer-which-do-i-use, https://livingatlas.arcgis.com/en/browse/.

Challenge 8, but they **build on and are complemented by the specific recommendations which can be found throughout this document, as well as those from the Data and Information Strategy** (and the pending Implementation Plan) and those of the other White Papers.

Finally, there is a lot of data and information already available, as well as data services/ and tools in place and/or under development. Identifying, coordinating, standardizing, and building on these existing efforts should be a key focus of Challenge 8.

2. Introduction

2.1. Background and context of Challenge 8

Ocean Decade Challenge 8, of the United Nations Decade of Ocean Science for Sustainable Development 2021-2030 (the 'Ocean Decade') seeks to create an adaptive and dynamic digital representation of the ocean to enhance decision-making and support sustainable ocean management.

Challenge 8 was initially inspired by the need for a common digital atlas of ocean information to address the prevailing and future societal pressures on the ocean and enable its protection and sustainable management (Ryabinin et al., 2019). However, in elaborating Challenge 8 it was recognized that this digital atlas or map could only exist within the context of a more comprehensive 'digital representation' of the ocean.

CHALLENGE 8

Through multi-stakeholder collaboration, develop a comprehensive digital representation of the ocean, including a dynamic ocean map, which provides free and open access for exploring, discovering, and visualizing past, current, and future ocean conditions in a manner relevant to diverse stakeholders.

Since the start of the Decade, the notion of a digital representation of the ocean has now matured into the global collection of interlinked and interoperable digital assets which can be applied to simulate and understand the global ocean's past, present, and future. These assets include FAIR data, information, software, applications (from simple programmes to models and digital twins), as well as the digital architectures and infrastructures which support and connect them.

While creating a comprehensive digital representation of the ocean is the ultimate objective of Decade Challenge 8, **the focus in this White Paper is to define the aspirations for delivering concrete outcomes and fostering the transformational change needed to create the enabling environment and initial digital assets, by 2030, that will enable us to fully deliver on the ambitions of Challenge 8 on the longer term.**

2.2. Overview of current work on the Digital Ocean in the Ocean Decade

The Ocean Decade Implementation Plan (IOC-UNESCO, 2021) states that *"Digitizing, accessing, managing and, most importantly, using ocean-related data, information and knowledge will be cornerstones of the success of the Ocean Decade."* The Implementation Plan further highlights that no single data, information and knowledge management infrastructure system will be able to support the Ocean Decade's ambitions. Rather, the focus should be on *"the collective design and construction of a distributed, multi-component digital network capable of representing the entire ocean system, including its social and economic characteristics"*.

To achieve these ambitions the Decade **Data Coordination Group (DCG)** was established to develop the **Ocean Decade Data and Information Strategy** (IOC-UNESCO, 2023) with the vision that by 2030, we will have: *"A trusted, inclusive, and interconnected ocean data and information ecosystem that is actively used for decision making to support sustainable ocean management."*

Many elements of such an ecosystem already exist. The Strategy aims to build on and leverage these components, infrastructures, systems, and capacities while also allowing for new data sources, information networks and solutions, developed by Decade Actions and relevant stakeholders, to be integrated as the needs of the Ocean Decade evolve. The Strategy Implementation Plan is currently being drafted by a **Data Strategy Implementation Group (DSIG)** to provide practical, lower-level guidance on how to co-develop and co-maintain such a digital ecosystem. The Plan emphasizes open, scalable, easily implementable, and responsive solutions and how these address specific challenges such as data interoperability, accessibility, and inclusivity. **This interoperable data sharing framework is essential for the realization of Challenge 8**. At the same time, realizing the strategic ambition and vision targets of Decade Challenge 8 put forward in this White Paper, will be critical to deliver on the Decade's Data and Information Strategy vision, i.e. to have in place by 2030 a trusted, inclusive, and interconnected ocean digital ecosystem that is actively used for decision making.

Three key components are recognized as critical for any fit-for-purpose digital ocean ecosystem: observations and data collection, data management and sharing, and data processing: analytics, modelling, and predictions. One could add the important group of intermediate users which provided downstream products and services to end-users. These components must be well coordinated, interconnected, and based on a common exchange framework. For that reason, three coordinating structures have been established to facilitate the development of the Decade's Digital Ecosystem, namely, the **Decade Coordination Offices for Ocean Data Sharing (DCO-ODS)**[3] and **Ocean Observing (DCO-OO)**[4], and the **Decade Coordination Centre for Ocean Prediction (DCC-OP)**[5] (see figure 1).

In addition, a Decade **Corporate Data Group** has been established to identify ways to unlock the enormous potential of private sector and industry data that is currently inaccessible to science. In addition to these entities and coordinating structures, there are also a large number of **Decade Actions that are identified as contributing to/addressing Challenge 8**. All of these are critical to the successful realization of the Challenge 8 Strategic Ambition.

[3] https://oceandatasharing-dco.org/

[4] https://oceandecade.org/actions/decade-coordination-office-for-ocean-observing/. Pertaining to the Ocean Observing part of the value chain, the recent GOOS Observation and Coordination Group Cross-Network Data Implementation Strategy should also be taken into account.

[5] https://www.mercator-ocean.eu/en/oceanprediction/

Figure 1. Main components of the ocean digital ecosystem and associated Ocean Decade coordination bodies

2.3. Importance and relevance of the Challenge for sustainable development

Creating a Digital Representation of the Ocean under Challenge 8 directly contributes to sustainable development by enhancing our understanding of the ocean, supporting informed decision-making, aiding in climate change mitigation, promoting sustainable economic activities, conserving biodiversity, and fostering global collaboration. This aligns with several of the United Nations Sustainable Development Goals, particularly those related to life below water (SDG 14), climate action (SDG 13), sustainable cities and communities (SDG 11), and partnerships for the goals (SDG 17). But when developing Challenge 8, we also need to consider SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production) and SDG 4 (Inclusive and Equitable Quality Education).

More specifically, achieving this challenge would lead to:

- **Enhanced Understanding of the Ocean**: A comprehensive digital representation of the ocean will greatly improve our understanding of ocean dynamics, processes and biodiversity. This knowledge is essential for managing ocean resources sustainably and for protecting marine ecosystems. [SDG 12 & 14]
- **Informed Decision-Making**: Policymakers, businesses, and marine environmental managers rely on accurate and timely information about the ocean to make informed decisions. A digital ocean provides the necessary data and insights to guide policies and actions that balance economic

interests with environmental protection. [SDG 11 & 12]

- **Improved Climate Change Research and Mitigation**: The ocean plays a critical role in regulating the Earth's climate. Understanding oceanic processes is vital for climate change research, including the study of carbon cycles, ocean acidification, and sea-level rise. This knowledge can inform strategies to mitigate and adapt to climate change. [SDG 13]
- **Disaster Prevention and Response**: Real-time monitoring and forecasting of ocean conditions can enhance disaster preparedness and response, particularly in the context of tsunamis, hurricanes, and other ocean-related natural disasters. [SDG 9 & 14]
- **A more Sustainable Blue Economy**: The blue economy encompasses a range of economic activities that rely on the marine environment, such as fisheries, tourism, and renewable energy. A digital representation of the ocean can support the sustainable development of these sectors by providing insights into resource availability, environmental impact, and sustainable practices. [SDG 9, 12, 14 & 17]
- **Biodiversity Conservation**: Understanding the distribution and health of marine ecosystems and species is crucial for biodiversity protection and conservation. Digital mapping and monitoring can help identify critical habitats, track species populations, and detect threats like overfishing and pollution. [SDG 14]
- **Educational and Awareness Building**: A digital ocean can serve as a powerful educational tool, increasing public awareness and understanding of marine environments and the challenges they face. This can foster a stronger connection between society, the broader public and the ocean, encouraging conservation efforts and responsible behavior. [SDG 4 & 14]
- **Global Collaboration and Data Sharing**: This challenge promotes international collaboration and data sharing. By pooling resources and expertise from around the world, initiatives that contribute to building a digital ocean can help overcome limitations of individual countries and create a more comprehensive and accessible global resource to the benefit of all. [SDG 9 & 17]

2.4. Methodology and guiding principles for the Strategic Ambition setting

This Strategic Ambition for Decade Challenge 8 was developed by a Working Group comprising a multidisciplinary group of experts, chosen for their diverse areas of expertise across the marine knowledge value chain and their regional representation. The process involved a series of brainstorming and drafting meetings and the iterative development of a background document from which this Strategic Ambition was extracted. Guidance and templates were provided by the Decade Coordination Unit (DCU) of IOC-UNESCO.

In setting this Strategic Ambition, the Working Group built on and aligned with ongoing work in the Decade in the context of the implementation of its Data and Information Strategy and in close collaboration with those entities referenced above who are supporting this implementation (IODE, DCG, DSIG, DCO-ODS, DCO-OO, DCC-OP, ...). Representatives from these entities participated in the expert group meetings as observers and acted also as interlocutors bringing the needs and priorities of Decade Actions (programmes and projects) active in this Challenge Area. Given also the crosscutting nature of this Challenge and thus its relevance to all Decade Challenges, the data and information needs identified by the other Working Groups were and will continue to be considered as critical in developing and realizing this Strategic Ambition.

Finally, the Strategic Ambition put forward in this document is guided by the following set of core principles:

- Create the enabling environment to work towards ever more comprehensive sets of digital representations of the ocean.
- Build on existing efforts where data communities have already organized themselves and on what is in place already, lifting up the core digital ecosystem components and interconnecting them, filling gaps if/where needed.
- Make maximum use of existing capacities and expertise, e.g. by leveraging experienced and established data centres to help assess data quality, metadata and ensure long-term data stewardship.
- Collect data once and use it many times by adopting FAIR and - where appropriate - CARE data principles which should underpin all Actions; ensuring adoption of common standards across disciplines as well as within them.
- Recognize that marine data is a public good and discourage cost-recovery pricing from public bodies.
- Develop a decision-making process for priorities that is user-driven.
- Accompany data and information with statements on ownership, accuracy and precision.
- Leave no one behind – providing equitable access to all, both to use and contribute to the digital ecosystem including data, products, tools and services.
- Connect the entire marine knowledge value chain, from observations and data collection to end-user applications, to develop a federated interconnected digital ecosystem.
- Ensure a multidisciplinary and multisectoral approach towards holistic solutions.
- Be transformative, including in engaging and working together with the private sector, to evolve and strengthen the global ocean digital ecosystem.

3. Strategic ambition setting

3.1. Analysis of user needs and priorities

Decade Actions are generating a wealth of marine knowledge outputs, delivering observations, data, processed information, and solutions relevant to their particular challenge area. These include methodologies, best-practices, technological innovations, as well as observations data themselves, derived data-products, maps, times-series, models, forecasts, digital twins and use cases. In order to generate these outputs, Decade Actions also require access to digital resources created by others. Facilitating sharing of and access to these marine knowledge resources in a way that is visible to and accessible by the global community is the first step in enabling co-design and development of solutions that can be implemented by decision makers.

Challenge 8 requires the development of a comprehensive digital representation of the ocean, *"through **multi-stakeholder collaboration**... in a manner that is **relevant to diverse stakeholders**."* This assumes and requires co-design and co-development with diverse stakeholders, to serve a wide range of users and contributors. Therefore, the term 'users' in this context does not only refer to those who may ultimately use the digital representations (as intermediate or end-users), but also to those communities who should contribute to developing both the digital representations (through shared data, information and knowledge) and the tools necessary to access and share these.

Given the breadth of this challenge area and its user-base, there is a need to categorize and prioritize its main user-groups to help define their needs and the actions required in developing this Strategic Ambition.

We consider that the **primary users** of Challenge 8 outputs **are the scientists, engineers and experts working** across Decade

Actions and related Decade coordinating bodies **to address the other Decade Challenges**. These include the experts who advise policy and decision making on national or international level. These actors are diverse in their data and information needs, their ability to use these resources (access, combine, manipulate them) and their potential to contribute to the Decade's digital ecosystem. At the same time, the Decade seeks to **serve the wider ocean (science) community** and stakeholders who are not necessarily operating within the Decade's universe, these can be considered **secondary users.**

The Decade also has the ambition to **'leave no one behind'**, therefore this challenge must also **deliver outputs that are relevant and useful for the widest possible range of users and stakeholders**, that is the eight billion people on this planet who should be able to access and use what is delivered by the Decade if so desired (non-professional stakeholders and **wider public as tertiary users**).

These broad user-groups will have different needs, both in terms of digital and thematic content, but also, in terms of their ability and capacity to access, use - and contribute to - the envisaged digital representation, and so can be categorized also according to their data literacy, as follows:

i) professional[6] **with** hands-on data-handling experience [Group 1]

ii) professional **without** hands-on data-handling experience [Group 2]

iii) non-professional, non-expert, i.e. broader public[7]. [Group 3]

For the professional users (group 1 and 2), there will be different levels of engagement and interaction both in the development and use of the Challenge 8 outputs, depending on their unique roles, user rights, and other factors which should be considered, as follows:

- **Those who are operating within the Ocean Decade** - i.e. the Actions (Programmes, Projects and Contributions including Implementing Partners), Coordinating Offices, Collaborative Centres, Working Groups and Communities of Practice as well as other UN organizations and/or bodies – **as well as those who are operating outside/beyond the Ocean Decade formal framework**; all of whom can and should be leveraged to co-design and co-deliver the Challenge 8 Strategic Ambition.
- **Different functions along the marine knowledge value chain**: from ocean observers/data-collectors (including from indigenous communities) to data management/ technical experts, data analysts and modelers, AI experts, and ultimately to diverse end-users (i.e. scientists and knowledge generators, policy advisors, decision-makers, digital twin developers, coastal communities, maritime operators, etc.).
- **Location and digital capacity**: Users from different regions with different levels of access to the internet, digital capacities, computing and other infrastructure, ...

Because we cannot pre-consider every possible use of the digital ecosystem envisaged, in developing the Strategic Ambition for Challenge 8, therefore, we consider the data and information needs and priorities identified by the other Decade Challenges[8], and their Vision 2030 working groups as proxy for the primary users (and contributors), representing as they do the key sustainability challenges for the Decade, and encompassing stakeholders from all the groups mentioned above.

[6] In this instance, professional refers to professional in the marine/ocean management/science/business domain

[7] By the broader public, we recognize that this is not a monolithic group but a community of sub-groups of varying degrees of education and capacity.

[8] https://oceandecade.org/challenges/

What all of the users for Challenge 8 have in common is that they need (i) the wealth of existing and accumulating ocean (multidisciplinary) data, information and digital products as well as (ii) tools/services for easily accessing and sharing this data, information and knowledge. These essential needs go hand-in-hand.

Therefore, we consider and define these user requirements as follows:

i) **Tools and services requirements**: The enabling environment facilitating the discovery, exchange and access to marine observations, data and information on the past, current and future state and use of the ocean, allowing the creation of the envisaged digital representation(s) *via multi-stakeholder collaboration*, ensuring also that the digital representations are developed in a way so that can be used by and are *relevant to diverse stakeholders*, bearing in mind the various categories of stakeholders, their needs and abilities.

ii) **Digital content requirements**: The envisaged digital representations including the underlying data and data-products (harmonized data layers, maps, time-series, models) facilitating also the development of overlying features, including digital twins.

3.2. Definition of the Strategic Ambition for the Challenge

3.2.1. The Strategic Ambition

By 2030, the Strategic Ambition for Ocean Decade Challenge 8 is to have in place the enabling environment for the creation of and access to an increasing number of digital representations and digital twin applications of the ocean as well as the underpinning data and information needed to develop them, delivering at minimum 10 societally relevant[9] global base-layers accessible via a global online Digital Atlas, complemented by a minimum of 10 local use cases (prioritizing SIDS and LDCs) to address challenges in using and contributing to the Decade's distributed digital ecosystem and to demonstrate and stress test its relevance, effectiveness and inclusiveness.

3.2.2. Tools, services and infrastructures

In delivering this Strategic Ambition we identify the need for the following concrete **tools and services** to be developed and in place by 2030:

i) A federated global **Ocean Data Discovery and Access Service (DDAS)** with a map viewer providing access to multi-disciplinary data, data products and information on the past and current state and use of the ocean, accompanied by an Ocean Data Help Desk and distributed Data Ingestion service; [for Group 1 above, i.e. professionals **with** hands-on data-handling experience].

ii) A global **Technical and Organizational Structure for Ocean Forecasting**, promoting harmonized methods, data standards, shared architectures, and tools to foster ocean prediction worldwide, leveraging the coming innovations derived from digital twins of the ocean; [for Group 1 and Group 2 above, i.e. professionals **with** hands-on data-handling experience and professionals without hands-on data-handling experience]

iii) A reference implementation for a global **Digital Atlas of the Ocean** (henceforth Digital Atlas), providing access to a minimum of 10 (or more) global bases layers and 10 (or more) local applications demonstrating its utility; [for Group 2 and 3 above, i.e. professionals **without** hands-on data-handling experience and the broader public].

iv) A series of **platforms, mechanisms and tools to store, share and exchange**

[9] Meaning relevant to achieving the Sustainable Development Goals

ocean information and knowledge beyond data and data products such as e.g. reports, recommendations, recommended practices, peer-reviewed papers, grey-literature, guidance documentation, models, software/tools, digital applications/services; [For all Groups]

v) **Enhanced facilities and resources for capacity development and training** tailored to the needs of users which are more actively promoted and used to drastically improve digital literacy across the Decade Actions. [For all Groups]

Each of these envisaged tools and services are further described and their requirements specified in **Annex 1** (Services, tools and infrastructures' requirements). While some of the components of these services are operational, most of them either do not exist yet, exist only partly as prototype/concepts, are not yet operational, or do not operate at the scale and level needed.

In developing these services, potential issues related to data privacy, cybersecurity, data authenticity, intellectual property and equitable access to technological infrastructure should be addressed to ensure the comprehensive development of the strategic ambition.

The architectures of the core data and information-sharing tools and services proposed should be compatible and able to speak to each other. In particular, the proposed DDAS and Global Forecasting Service should be interoperable and compatible with the architecture of other decision support tools and applications proposed or currently under development, such as for example the digital twin application architecture as being developed by the Digital Twins of the Ocean Programme DITTO.[10] and its associated endorsed Action TURTLE.[11], among others.

[10] https://ditto-oceandecade.org/

[11] https://ditto-oceandecade.org/affiliated-projects/interoperability-architecture-for-a-digital-ocean-turtle/

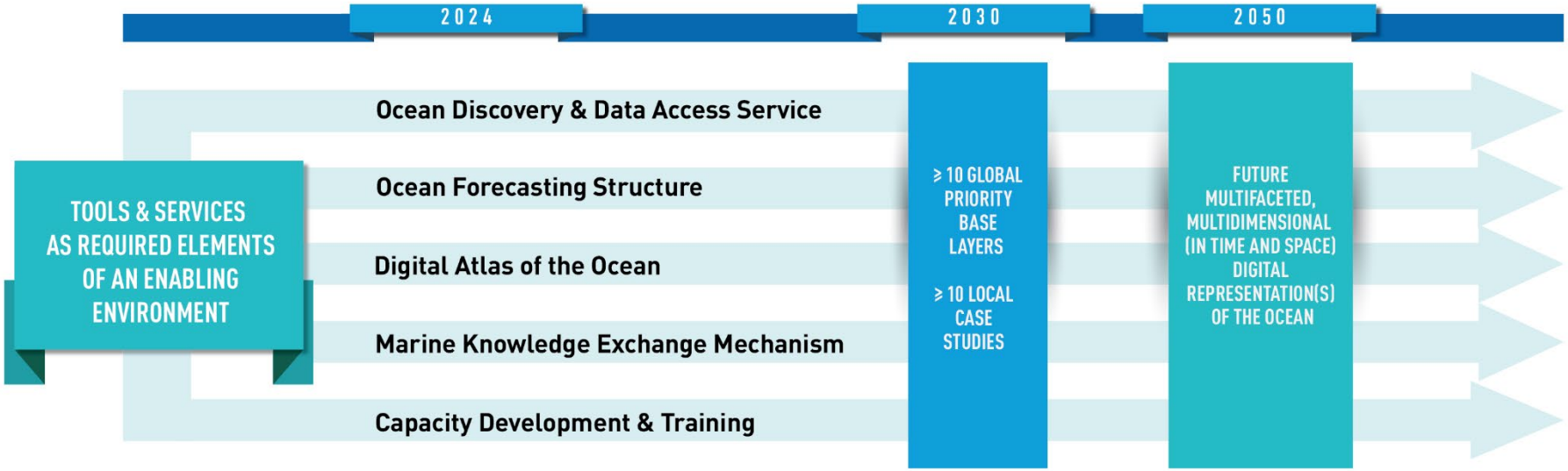

Figure 2. *Graphical representation of the Challenge 8 Strategic Ambition setting*

3.2.3. Priority datasets, global data layers and local case studies

Rather than starting by targeting priority datasets, for the Strategic Ambition of Challenge 8 we propose to work the other way around and focus on prioritizing and making available a series of **societally relevant global priority base layers**, or flagship data-products per challenge area, that deliver solutions to address the other (thematic) challenge areas and which will act as drivers to identify and address underlying data gaps and interoperability issues. While the complexity of this is not to be underestimated, regional experience[12] has shown that the potential of a common, desired data-product/layer creates the incentive for actors to reach agreements on standards, overcome challenges and develop a common approach, building on and expanding existing communities of practice.

Furthermore, these global/flagship data products should be complemented with a selection of **local case studies** (prioritizing the SIDS and LDCs) focusing on providing marine and coastal data and data products at a higher resolution to highlight concrete bottlenecks along the marine knowledge value chain, stress test the ability of various communities to access the Decade's digital ecosystem and address potential equity ramifications of reliance only on digitized, quantitative data inputs.

We identify the need to elaborate transparent processes as well as guiding principles and criteria to (i) identify and select priority base layers and local case-studies for ingestion into the Digital Atlas; and (ii) co-design/co-develop the selected base layers. The foundations for these can be found in **Annex 2**.

We **call for maintaining an Expert Group beyond the delivery of this White Paper, as an independent expert group to:** (i) oversee the identification and selection of priority base-layers and local case studies for integration into the global Digital Atlas; (ii) act as custodians of the selected priority base layer co-design and co-development process, overseeing the development and implementation of the guiding principles by the communities of practice developing the selected data-layers as well as their ingestion into the Atlas; and (iii) oversee the progress made overall to achieving the ambition targets of Challenge 8, using the set milestones and KPIs (see Section 4).

Indicative potential base-layers and local case-studies proposed by expert working group members are provided in **Annex 3**, among others based on priority gaps and needs identified in the (nascent) strategic ambitions of the other challenges.

Important considerations

Challenge 8 aspires to enable creation of digital representations of the ocean that are built on broad, inclusive and equitable foundations, drawing on a variety of data that reflect environmental and human variables while convening with FAIR[13] and CARE[14] principles.

Ocean data varies across characteristics including (but not limited to) geographic scale and resolution, temporal scale and resolution, findability, interoperability, digitization, and the adherence to FAIR and CARE[15] principles. The relationships between these categories are likely predictable. For instance, data that are

[12] GEBCO https://www.gebco.net/, EMODnet (https://emodnet.ec.europa.eu/en/bathymetry#bathymetry-approach, https://emodnet.ec.europa.eu/en/euseamap-2021-emodnet-broad-scale-seabed-habitat-map-europe); FAO WECAFIS https://www.fao.org/wecafc/data/wecafis/en/

[13] Findable, Accessible, Interoperable, and Reusable, https://www.go-fair.org/fair-principles

[14] Collective Benefit, Authority to Control, Responsibility, Ethics, https://www.gida-global.org/care

[15] In considering FAIR and CARE aspects, we note and build on the significant ongoing work on interoperability to develop common standards, ontologies, best practices, etc., by Decade entities implementing the Decade's Data and Information Strategy.

easily findable, broad scale and digitized (e.g., commercial fisheries data, census data) are less likely to meet CARE criteria, while data that do meet such criteria (e.g., Indigenous knowledge or co-produced human use, socio-economic, and environmental data) are likely very local in scope and may not yet be available in digital formats. As a result, easily ingested 'big' data will be biased towards certain types of sources. Reliance on such data alone will erase the activities, values, and knowledge of sectors of society (e.g., Small Island Developing States, stateless peoples, Indigenous fishers) that are poorly represented in the most accessible datasets, thereby perpetuating and worsening inequity, while violating CARE principles.

We highly recommend that any approach to meeting this challenge should include concrete, clear, measured, and effective measures to broaden **digital representation of under-represented data sources and types**. Where the lands, rights, or interests of indigenous peoples are involved, clear implementations of the CARE principles should be present, having been co-developed with indigenous communities from the earliest phase possible.

We also note that the data needs and priorities identified by the other Working Groups of the Vision 2030 process are also subject to some of the challenges already outlined above, in particular those concerned with human activities, co-creation, capacity sharing, and/or Indigenous partners. There is also a need to identify the data requirements for various latitudes and settings by integrating top-down scientific expertise combined with bottom-up practices and needs. A **summary overview of some of the main trends and specific priority data needs identified by other Decade Challenge White Papers can be found in Annex 4**.

Finally, it is important to clarify that, while there is a clear target to generate and provide priority base layers, which will by necessity identify, unlock, and promote harmonization of, underlying datasets, the Strategic Ambition for Challenge 8 put forward by the Working Group does not ignore the needs expressed by so many Decade actors who are struggling to find out what marine data and data products exist already that could be accessed and used, as highlighted in the Decade's Data and Information Strategy. **Unlocking as much existing (and newly collected) ocean observations, data and data products as possible by making them discoverable and accessible is one the key objectives** of the Ocean Data and Information System (ODIS) whose development and further deployment is at the core of the Decade's Ocean Data 2030 Programme**, aligned with this Vision Paper's ambition for Challenge 8** to put in place by 2030 an operational federated DDAS.

3.2.4. Partnerships and resources

The achievement of the Challenge 8 Strategic Ambition by 2030 is critically dependent on the mobilization, engagement, and collaboration of a wide array of partners from across the globe. This includes governments, United Nations agencies, scientific communities, private sector entities, NGOs, and local communities, among others. Recognizing the central role that effective partnerships have to the success of the Decade, our approach to partnerships and resources for developing a comprehensive digital representation of the ocean is multifaceted and inclusive. To operationalize this vision, we propose the following actions, aligned with the principles laid out in the Decade's Data and Information Strategy:

- **Developing Value Propositions**: For each identified requirement and vision target, whether it be services, infrastructures, tools, or content, a detailed value proposition should be developed. This value proposition will need to outline the challenges currently faced by intermediate and end-users and the solutions offered by the proposed outputs of Challenge 8. Where not existing yet, this should include an estimation of the efforts and resources required for delivery, thereby serving as a compelling call to action for potential partners and funders.

- **Multi-sectoral Collaboration**: Encouraging and establishing multi-sectoral collaborations will be key. This includes partnerships with tech companies for innovative solutions, academic institutions for cutting-edge research, government agencies for policy integration and support, and NGOs and local communities for ground-truthing and ensuring that the digital ocean representation is relevant and accessible.
- **Leveraging Existing Initiatives and Infrastructures**: Wherever possible, Challenge 8 will build on and integrate with existing initiatives, infrastructures, and data platforms to avoid duplication of effort and to maximize the utility of existing resources. This includes engaging with existing data networks, observatories, and platforms that align with the Decade's vision for an interconnected and interoperable digital ecosystem.
- **Engagement with the Private Sector**: Recognizing the pivotal role that the private sector can and should play in providing technological innovations, infrastructure, and funding, targeted engagement strategies should be developed and implemented. This includes exploring opportunities for public-private partnerships that can bring new investments, technologies, and capabilities to bear on the challenge of creating a digital representation of the ocean. Where examples of applications or platforms exist in the private sector that could be adapted through collaboration or investment, as highlighted in this White Paper, we encourage exploration of these opportunities, avoiding becoming locked-in and maintaining freedom of use and neutrality. It is recommended to develop a specific roadmap with actions to identify key private sector players and follow up on specific opportunities to engage with industry and build the capacity for delivering on the digital ocean's strategic ambition.
- **Capacity Building and Resource Sharing**: In line with the Decade's Data and Information Strategy, resource mobilization will be necessary to support the development of the digital ecosystem backbone and end user services, and also for capacity building in data management, sharing, and utilization among all stakeholders, especially those in underserved regions. This ensures that the benefits of Challenge 8 are widely and equitably distributed. Partnerships should be fostered to develop mechanisms to share resources and infrastructures, e.g. for sharing high performance computing infrastructure to run digital twins.
- **Sustainable Funding Mechanisms**: A strategic approach to securing sustainable funding must be developed and implemented, identifying and engaging with a range of funding partners, including governmental, intergovernmental, private philanthropy, and the commercial sector. Innovative financing mechanisms should be explored to support the long-term sustainability of the interoperable data sharing framework and digital ecosystem underpinning the delivery of a fully comprehensive Digital Representation of the Ocean.
- **Transparency and Openness**: All partnerships and collaborative efforts need to be guided by principles of transparency, openness, and mutual benefit, ensuring that the development of the digital representation, as envisaged here, is a shared, global endeavor that aligns with the overarching goals of the UN Decade of Ocean Science for Sustainable Development.

Implementing these actions will be critical to mobilize the partnerships and resources necessary to achieve the ambitious goal of developing a comprehensive digital representation of the ocean. As far as possible in outlining this Strategic Ambition, we have name-checked relevant actors, organizations, networks, and partnerships which should be

mobilized or engaged with to create or further develop the required services and digital contents identified as part of this Strategic Ambition.

3.2.5. The regional dimension

While this White Paper presents a high level global strategic vision for Challenge 8, we emphasize the importance of the regional dimension within the framework of developing a digital representation of the ocean to ensure an inclusive and effective approach, able to capture the diverse and dynamic nature of marine environments across the globe. This is important given the inherent spatial variability of the ocean and the unique challenges and opportunities presented by different marine regions. By harnessing the strengths of regional collaborations, data sharing, and capacity building, we can ensure that the ambitions of the Ocean Decade Challenge 8 are realized in a manner that respects the diversity and complexity of the world's marine environments and ocean communities. A few considerations with regards to the regional dimension:

First, the United Nations Decade of Ocean Science for Sustainable Development adopts a decentralized coordination structure that emphasizes regional collaboration through Decade Collaborative Centres (DCCs), fostering partnerships that are attuned to local and regional priorities and capabilities. These should be activated to contribute to realizing the strategic ambition among others by promoting and implementing the Decade's Data and Information Strategy and Action plan at the regional level.

Second, the Intergovernmental Oceanographic Commission (IOC) and many other UN organizations contributing to the Ocean Decade employ a regional approach that further underscores the importance of tailoring scientific, policy, and capacity-building efforts to the specific needs of various subregions. Similarly, the International Oceanographic Data and Information Exchange (IODE) program operates through regional nodes, ensuring that data sharing and information exchange mechanisms are responsive to regional contexts. The Ocean Teacher Global Academy (OTGA) leverages regional training centres to deliver education and capacity-building programs that are both globally informed and regionally relevant.

Thirdly, digital twins of the ocean are being developed with a keen awareness of regional specificities, often focusing on scales ranging from local bays to larger regional basins. These digital representations enable detailed exploration and understanding of marine processes at scales most relevant to regional stakeholders, from policymakers to researchers and local communities. This granularity is crucial for developing effective management strategies, conservation efforts, and sustainable development initiatives that are grounded in the reality of regional marine settings.

Moreover, the proposed global Technical and Organizational Structure for Ocean Forecasting is designed to enhance regional forecasting capabilities. By integrating local data and leveraging regional expertise, the forecasting service aims to deliver actionable insights that support regional decision-making, risk management, and sustainable use of marine resources.

Acknowledging the significance of the regional dimension, this white paper advocates for the inclusion of local case studies into the Digital Atlas from each regional basin. These case studies serve as key examples of how digital ocean representations can be tailored to address regional challenges, providing valuable insights into the efficacy of data-driven approaches in diverse marine contexts.

3.2.6. Technology and innovation

The Decade calls for transformation. Technology and innovation will power this transformation and are enablers of the Strategic Ambition for Challenge 8. We will rely on the advancement of existing technologies, bringing the internet of things (IoT), machine learning and artificial intelligence (ML/AI), virtual and augmented reality (VR/AR), serious gaming and other innovations into existing

ocean observing, data analysis, and modelling environments to reach the vision targets. Success will also require the deployment of new technologies such as automated and cost-effective sensors, drones, and sampling systems which are natively networked to the Decade's distributed digital systems described above. If implemented and governed responsibly, these assets will allow for ever more comprehensive, inclusive, and useful digital representations of the ocean and rapidly enhance our ability to fairly and sustainably manage the ocean.

Digital representation: from data lakes to digital twins

The operational Ocean DDAS which we call for in this White Paper must be capable of interfacing with many sources of data and information, with drastically different architectures. Collectively, these sources will constitute the Decade's distributed data lake - a repository of structured and unstructured data. Public and private cloud services, secure and encrypted archives, simple local servers, microdata services, and digital twin systems will all require equitable interfaces to the DDAS to be detectable as parts of this lake.

As global capacity shifts, the ability to interface with commercial cloud services, where organizations and increasingly also governments are renting their IT services, will be increasingly important. Mirroring major subsets of or complete copies of data in such major cloud computing facilities could be very beneficial for many applications and delivering digital solutions. This would reduce the access demands on the government services and allow near-compute localization and improved reliability and performance of both commercial and public applications deployed in such clouds.

To fulfil this vision, the data lakes being assembled across the ocean community need to be coordinated and interoperable, with cloud-optimized and near-compute solutions popularized to enhance performance and reduce the immense carbon emissions resulting from modern computational demand. With improved coordination and interoperability, users will experience a seamless flow of data and we will have the basis to mature these data lakes into fully interoperable data spaces. Complex environments, such as digital twins and virtualization engines, will greatly benefit from such systems, being able to discover and source data (as well as software and other assets) far more effectively and with reduced human intervention. Where the DDAS detects that data is dense and interoperable enough, a twinning solution can be deployed more rapidly. In this environment, the Decade's responsibility is to ensure that networked data flows and solutions are usable by all, and commercialization does not result in barriers to accessing public data (be that through access or by the use of proprietary standards and/or software).

Naturally, we recognize that such transformation raises concerns about creating and governing rights over copies of data and data products and propose that these discussions on how to deal with e.g. duplicate copies (e.g. via consistent tracking) are advanced in the context of Decade's DSIG and the Corporate Data Group, proposing solutions that balance interests.

Artificial Intelligence and Digital Representations

Artificial intelligence (AI) is already extensively utilized to process data and generate knowledge. It is used in climate and oceanographic modelling, taxonomic identification, automated workflows, and is therefore already included in many marine knowledge value chains. Recent advancements such as Large Language Models (LLMs) are accelerating the pace and also lowering the bar to analyze data, albeit raising new challenges in error detection and unbiased training. Together, these technologies could present new opportunities in the context of this challenge, including the following:

- Unlock unstructured data from publications and grey literature to provide

or improve observational datasets to the DDAS and Ingestion Service.

- Glean new insights from structured and unstructured data together with cheap storage and computing power.
- Augment data sets through accelerated gap filling and cross-validation, enabling more accurate predictive modelling with higher temporal, spatial and thematic resolution.
- Enhance data sharing and interoperability through, e.g., liberating source data in publications, multimedia files, industry and government archives, and other dormant repositories.
- Accelerate the extraction of meaningful information using open-source libraries including powerful AI tools, for example for extracting new information from large amounts of underwater videos, or sonar data.
- AI assistance has the potential to lower language and know-how barriers, empowering more people to generate and visualize knowledge and ultimately take more informed decisions in the blue economy.
- AI could potentially be used to capture traditional knowledge that cannot easily be put into databases. An important caveat is that if AI were to be used to interpret traditional knowledge, the training steps would be biased towards certain ways of using knowledge and language and this may be flawed given inherently different world views. Pilots in specific regions could be used to see how the training would work.

While AI has raised a lot of expectations, effective AI relies on large, unified, and unbiased collections of data offered in a form that can be ingested as a whole. The Common Crawl and WebImageText are examples, with communities such as Hugging Face and KAGGLE creating new communities of practice[16].

To allow AI to contribute to improve our understanding of the ocean, the UN Ocean Decade should strive to align its data and software to emerging global norms for AI-readiness, actively contributing to their development to ensure the needs of the ocean community are met. The DDAS, Digital Atlas, and other components envisaged in this White Paper must also factor AI-readiness into their implementations and ensure compatibility between those implementations.

While large commercial and operational efforts (e.g., industrial fishing and aquaculture, offshore wind, core oceanographic monitoring) may create standardized streams of real-time data which can be readily converted to AI-ready forms at high volumes, there are many other communities generating data in heterogenous and/or unstandardized forms that inhibit their use, and thus biasing the training of ML-based solutions. Further, key metadata to prevent AI agents from introducing bias or error into their training sets are often not available. As we call for the sharing of more ocean-relevant data, including socio-economic and cultural data, to face the Decade's Challenges, there is a need to account for how the inclusion, exclusion, or misrepresentation of this data will impact AI-powered solutions and the digital representation of the ocean. New expert groups on AI governance and ethics are needed, as well as capacities to monitor AI solutions to detect and resolve issues rapidly.

The Decade's Data and Information Strategy Implementation Plan will elaborate and add more detail on the technical and innovation considerations and requirements for the decade's digital ecosystem.

[16] https://commoncrawl.org, https://github.com/google-research-datasets/wit, https://huggingface.co, https://www.kaggle.com

3.3. Integration, synergies and interdependencies with other Challenges

This Strategic Ambition is interdependent on the priority data and information needs identified by the other challenges. These will contribute to identifying the priority-base layers and local case studies via the consultation and selection process outlined in Section 1.1, but also in the development of fit-for-purpose tools and services to share and serve the knowledge products developed by Decade Actions and relevant communities.

Challenge 8 focusing on creating a digital representation of the ocean, is a foundational element that underpins the success and efficacy of all other challenges. This challenge is not isolated but deeply integrated with, and dependent on, the achievements and advancements made in the other nine challenges. It offers a unique platform for synergies, fostering a comprehensive understanding and management of the ocean's resources, health, and sustainability. Below, we explore some of the key aspects of integration, synergies, and interdependencies between Challenge 8 and the other nine Ocean Decade Challenges.

Ocean Observing and the Digital Ocean

There is a particularly strong connection between Decade Challenge 7, focusing on enhancing and expanding ocean observing systems and capabilities, and Challenge 8 which involves nurturing of an interconnected digital ecosystem enabling the creation of a comprehensive digital representation of the ocean. Both Challenges and their objectives are intrinsically linked and entail a vital synergy underpinning all other Challenges which is crucial for the success of the UN Decade of Ocean Science. This connection emphasizes the integration and interdependencies between the advanced observation technologies and the creation of an accurate, dynamic digital representation of the ocean. By collecting comprehensive, high-quality data through sophisticated ocean observing systems, Challenge 7 lays the foundational framework necessary for Challenge 8's ambitious goal to digitally mirror the marine environment. This collaborative approach not only maximizes the utility of the data collected but also aligns with the Decade's Data and Information Strategy, ensuring that information is shared, accessible, and actionable. Together, these challenges provided the basis for developing a more profound understanding of oceanic processes, enhance predictive capabilities for climate change and maritime hazards, and support the sustainable management of ocean resources, highlighting the critical nature of their interconnectedness for the Decade's overarching objectives.

Given the above, we should ensure that by 2028, collectively we have actively engaged in the planning for full and visible participation of the Ocean Decade in the OceanObs'29 Conference to be hosted in China in 2029, to ensure that the efforts towards achieving Challenge 8, Creating a Digital Representation of the Ocean, and its applications are fully linked into the framework for ocean observing.

Ocean Health and Pollution

Digital representations can significantly enhance our understanding of marine pollution sources, distribution, and impacts, contributing to more effective mitigation strategies. By integrating data from Challenge 1 ('Understand and beat marine pollution') and Challenge 2 ('Protect and restore ecosystems and biodiversity'), digital platforms can model pollution dispersion, identify hotspots, and assess ecosystem health. This integrated approach enables targeted clean-up efforts and the monitoring of restoration activities' effectiveness.

Sustainable Ocean Resources and an Equitable Ocean Economy

Challenges focusing on sustainable fisheries, aquaculture, ocean-based energy solutions, and wider ocean economic activities (Challenge 3 'Sustainably feed the global population', and Challenge 4 'Develop a sustainable and equitable ocean economy') can greatly benefit from the digital ocean framework. By providing detailed, dynamic representations of marine resources, habitats, and human activities,

Challenge 8 supports sustainable management practices. For instance, digital twins can simulate the impacts of fishing practices, aquaculture operations, or renewable energy installations on marine ecosystems, facilitating the development of strategies that balance economic benefits with conservation needs.

Climate Change, Ocean Hazards and Community Resilience

The understanding of ocean-related climate processes (Challenge 5 'Unlock ocean-based solutions to climate change') and how these, together with other ocean hazards, will impact maritime activities and coastal communities (Challenge 6 'Increase community resilience to ocean hazards') are critical areas where digital representations offer invaluable insights. By synthesizing data on sea-level rise, ocean acidification, extreme weather events, maritime activities and coastal communities, digital models can enhance disaster risk management, climate change mitigation, and adaptation strategies. This integrated data approach supports informed decision-making to protect coastal communities, infrastructure, and marine biodiversity.

Innovative Technologies and Capacity Building

The development of digital ocean representations relies on innovative technologies and the broadening of capacity across global stakeholders from the collection of data (Challenge 7 'Expand the Global Ocean Observing System') to the development and application of knowledge products. Challenge 9 ('Skills, Knowledge, and Technology') directly supports Challenge 8 by developing the necessary technological and human capacities for advanced data observation, analysis, modelling, and visualization. Meanwhile, Challenge 10 ('Change humanity's relationship with the ocean') focuses on ensuring that these innovations and knowledge are accessible and beneficial to all, promoting equitable participation in ocean science and governance. The cross-fertilization between these challenges ensures that digital representations are not only cutting-edge but also inclusive and widely adopted.

Data Integration and Accessibility

At the heart of Challenge 8 is the integration and accessibility of ocean data. This challenge acts as a central hub, drawing on data generated from all other challenges, whether related to biodiversity, pollution, climate change, or human activities. By creating a unified, accessible digital ocean, it ensures that data collected from disparate sources and projects are harmonized, made interoperable, and available for analysis, fostering a holistic understanding of ocean systems.

In conclusion, the interdependencies between Challenge 8 and the other Ocean Decade Challenges underscore the importance of a collaborative, integrated approach to ocean science and management underpinned by an enabling interoperable ocean data and information sharing environment. Digital representations of the ocean serve as a crucial foundation for synthesizing knowledge, informing policy, and guiding sustainable practices across all challenges. By leveraging these synergies, the Ocean Decade initiative can achieve its vision of "the science we need for the ocean we want," ensuring a sustainable and resilient future for our global ocean.

4. MILESTONES AND INDICATORS

Linked to the main Vision 2030 targets for Challenge 8, Table 1 below summarizes some of the main milestones along the way towards achieving these targets by 2030, together with a number of Key Performance Indicators (KPIs) for measuring progress towards success. A list of complementary KPIs which could be considered for monitoring and evaluating progress towards expected outcomes for Challenge 8 can be found in Annex 5.

Table 1. *Key milestones and indicators to measure progress and success towards the main Vision 2030 Targets*

VISION TARGET TO BE ACHIEVED BY 2030	MILESTONES ON THE ROAD TO SUCCESS	KPIS FOR PROGRESS ASSESSMENT
<u>Fully operational federated Global Data Discovery and Access Service (DDAS)</u> *Who to lead:* DSIG and Ocean Data 2030 Programme, IODE <u>Help-desk and Ingestion Service</u> **Help desk and distributed Ingestion Service included as a permanent feature in DDAS service post-Decade** *Who to lead:* DCO-ODS, Decade Data experts (Working Groups), IODE	**DDAS milestones:** · Specifications and development plan drafted by Data Strategy Implementation Group (DSIG) and Ocean Data 2030 Programme (2024) · Dedicated resources mobilized (2026) · Prototype ready (2028) **Help desk milestones:** · Prototype help-desk available online via the website of the DCO for Ocean Data Sharing and trailed at Decade conference in Barcelona (2024) · Commitments from relevant bodies to provide expertise to support help-desk facility (2025) · Satisfaction survey of help-desk facility is issued, and feedback incorporated in new iteration (2026)	Amount, geographic, and thematic coverage of data available; Times of access via other databases to the Digital Atlas, and vice versa Number of questions received and resolved using the online Help desk; percentage geographic coverage of source of questions
<u>Operational global Technical and Organisational Structure for Ocean Forecasting</u> *Who to lead: The DCC Ocean Prediction to coordinate with its technical working group and relevant Decade Actions*	· A Global community organized around regional Teams to promote the implementation of ocean forecasting systems worldwide (2025) · A world Atlas to identify the ocean forecasting community stakeholders, prediction services and applications (2025) · An architecture for ocean forecasting based on clearly defined tools and data standards (2026) · An Operational readiness level with an associated tool to compute it that will serve as a guideline for implementation of best practices (2027) · A demonstration of at least 10 forecasting services fully integrates into Digital Twins (2028)	Number of systems included in the world Atlas Number of systems around the globe estimating its Operational Readiness Level Number of systems integrated into Digital Twins
Global Digital Atlas of the Ocean with full functionality for viewing and interacting with diverse layers and data products *Who to lead:* Call for a new programme mobilising providers, implementers and users for co-design and co-development	· ICAN and members of the global community of practice on digital coastal and marine atlases to further elaborate and define the functionality of the Atlas, cost it and recommend it as Decade Programme (2024) · Call issued for a new Decade Programme to create a Global Digital Atlas (2025) · Resources mobilized (2026) · Prototype Atlas available and survey to solicit initial feedback towards co-design is issued (2028)	Number of views and (requests to) download map layers or metadata via the Global Digital Atlas; Amount, geographic and thematic coverage of data products available

Global Base layers & Local Case Studies **Minimum 10 societally relevant layers available via Global Digital Atlas** *Who to lead:* Relevant communities developing existing products led by Decade Actions working on the thematic challenges and identified via a transparent process	· Minimum 10 potential layers and communities of practice identified and prioritized (2024) · Minimum 10 priority layers agreed and associated communities of practice committed (2025) · Methodology and approach agreed and made available via knowledge sharing platform (2026) · Preliminary layers available via prototype Atlas (2028)	Number of societal relevant layers available via Global Digital Atlas and usable on mobile apps
Minimum 10 local case studies available via Global Digital Atlas *Who to lead:* Relevant communities active in Decade Actions working on the thematic challenges and identified via a transparent process	· Minimum 10 potential case studies and leads identified and prioritized (2024) · Minimum 10 potential case studies agreed (2025) · Work initiated on all case studies. (2026) · Stakeholder satisfaction survey is issued, and results incorporated. (2026) · Preliminary data products available via prototype digital Atlas (2028)	Number of local case studies available via Global Digital Atlas and usable on mobile apps
Sustained platforms, mechanisms and tools actively used to store, share and exchange ocean information and knowledge from/by Decade Actions *Who to lead:* IODE working group on marine knowledge exchange	· Working group established, key recommended platforms and mechanisms identified (2025) · Promo-campaign to position platforms as knowledge sharing repositories/mechanisms (2026) · Resources mobilized and commitments secured for long term maintenance of recommended platforms/tools (2028) · All Decade outputs available via open platforms/tools (2030)	Number of platforms joined the marine knowledge exchange mechanism; Frequencies of discussion/ dialogue logged
Enhanced digital literacy through dedicated Capacity Development & Training resources and facilities *Who to lead:* IODE-OTGA, Capacity Development Facility, GOOS&IODExperts and Decade Actions working on Challenge 9; Set-up a Task Force or Working Group to assess needs and mobilise resources for enhanced capacity development and digital literacy training across facilities/initiatives.	· Data Literacy Task Force or Working Group established (2025) · Consultation/assessment of existing capacity development and training resources, gaps and needs completed, in particular with usability and inclusiveness of developing elements of digital representation; · Recommendations and workplan for enhanced resources and activities complete (2026) · Feedback incorporated in co-creation. · Resources mobilized and commitments secured for further enhancement of training and capacity development resources and activities (2027) · Story-telling apps developed for each priority-base layer (2028) · Multilingual courses available to boost data management and sharing capability, in particular in relation to using and contributing to the core services underpinning the Decade's Digital Ecosystem (2029)	Modules produced; training held; number of participants attending workshops/trainings; Communities of Practices engaged, number of stakeholder groups contributing.

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Annex 1. Services, tools and infrastructures' requirements

In identifying the infrastructures, tools and related services needed to enable the development and accessibility of the digital representation for all contributors and users, we identify the following requirements:

(i) Federated Global Ocean Data Discovery and Access Service (DDAS)

In line with the Decade's Data and Information Strategy's vision of a functional, inclusive globally distributed data and information service that provides timely access to data and information about the past, current and future state of the ocean, we support the urgent **need for an operational global Ocean DDAS** for experts with hands on expertise in data-handling, allowing discovering, retrieving, viewing and downloading data (and information).

This Service should:

- Enable Decade Actors and wider stakeholders to discover, access, and share data at an unprecedented scale.
- Be compatible with the envisaged Digital Atlas (below) and allow users to easily discover, access and download the data underlying the base layers and local case studies, as well as the data products themselves.
- Have an architecture that is compatible with global norms of data discovery and sharing over the web, as well as the architecture of other core service and/or decision support tools/applications e.g. the ocean forecasting system being developed by the DCC-OceanPrediction; the Digital Twin application architecture as being developed by DITTO/TURTLE etc.
- Be developed to allow interfaces adapted to the needs of users with different digital capabilities and to allow inclusion of socio-economic data and atypical sources of data (new types of data, CARE-compliant data, …).
- Be built upon existing platforms, infrastructures, programmes, federating distributed data/metadata nodes already in place.

In considering what exists, and what could be further developed, the Decade's Ocean Data 2030 Programme has ambitions to further develop, populate and expand the scope of the Ocean Data and Information System (ODIS) Federation, and interfacing it with other digital systems. We call for a follow up of the Ocean Infohub[17] project in 2024 and onwards to drive this development, as a core part of this vision. Other relevant Actions providing critical data infrastructures include the World Ocean Database Programme and a range of regional data services which already provide a wealth of resources and services that should be part of the solution.

We call on the Decade Data Strategy Implementation Group (DSIG) to define a practical pathway for Decade stakeholders to co-develop and co-maintain fully functional federated global Ocean DDAS. The DDAS should drive dynamic map viewers for use by (among others) the Digital Atlas reference

[17] Ocean Infohub is the operational development pilot project for ODIS which aims to connect local national and regional data systems across the world via agreed standards.

implementation. We invite the Ocean Data 2030 Programme to coordinate the co-implementation of these with the Decade community and partners.

To be able to use and contribute the digital ecosystem envisaged by the Decade's Data and Information Strategy, Decade Actors have also identified the need for support and guidance to adhere with data management and sharing requirements, with a growing request that there should be a permanent data-sharing virtual/distributed helpdesk service to support them. With this in mind, the Ocean DDAS should be supported by a permanent **Data Help Desk and distributed Data Ingestion** service.

The data helpdesk should:

- Provide an online point of access where stakeholders can submit questions/requests for support, connected to a team of data managers and experts to receive guidance on all ocean data related aspects from collecting data, making a data management plan, metadata, etc.
- Provide support and facilitate access to a distributed Data Ingestion Service(s) to assist diverse stakeholders to share their data according to FAIR and CARE principles.
- Facilitate multi-lingual and natural language querying.
- Consider both contributors and users of the digital representation at varying levels of ability and capacity access), to maximize sharing and use of Decade data resources.
- Provide access to an online, interactive Ocean Data Toolkit including and linking to resources, including template for Data Management Plans, community best practices and standards, data policies and principles and distributed ingestion services.

We call for the DCO for Ocean Data Sharing to coordinate with the global data management Community of Practice, and in particular with the IODE network of National Oceanographic Data Centres (NODCs), Associated Data Units (ADUs) and programme components (ODIS, OTGA, OBIS), to develop and trial a blueprint for a permanent Data Help Desk service. This could be a shared service driven by the DCO for Ocean Data Sharing but supported by a distributed network of experts with the view to be integrated in a long term global federated DDAS service post-Decade in close collaboration with IODE.

(ii) Global Technical and Organizational Structure for Ocean Forecasting

Ocean forecasting plays a pivotal role in the realization of Ocean Decade Challenge 8 creating a digital representation of the ocean. It is crucial for assessing future scenarios, enhancing disaster prediction, and improving climate change predictions, thereby informing mitigation strategies and other vital decision-making processes. By leveraging advanced technologies to simulate and predict oceanic conditions, scientists and policymakers can gain invaluable insights into the complex interactions within marine environments. This, in turn, facilitates the anticipation of extreme weather events, the assessment of climate change impacts, and the identification of sustainable practices for ocean use. Ultimately, the development of a comprehensive digital representation of the ocean empowers stakeholders to make informed decisions, fostering resilience and promoting the sustainable management of ocean resources for future generations.

Despite its critical importance, ocean forecasting remains underutilized, constraining our ability to effectively monitor and manage our ocean, especially in coastal regions. The complexity of operating and maintaining these systems, coupled with a lack of shared tools, data standards, and best practices, has created significant barriers. Therefore, there is an **urgent need to establish a comprehensive Global Technical and Organizational Structure for Ocean Forecasting**. This initiative should leverage advancements such as digital twinning and new AI technologies to address these challenges.

This envisaged structure will promote ocean forecasting worldwide by:

- Organizing a cohesive community dedicated to ocean forecasting, inclusive of diverse stakeholders and organized by geographical regions. This collaborative approach will facilitate knowledge sharing and will be instrumental for the identifications of gaps and ways forward.
- Collaborating closely with the Global Ocean DDAS to break down data silos and seamlessly integrate ocean forecasting and observations.
- Developing and disseminating best practices, tools, and data standards in partnership with relevant programs such as Foresea, Ocean Practices, CoastPredict, GEMS-Ocean and others, alongside the Expert Team on Operational Ocean Forecasting Services (ETOOFS).
- Establishing technical frameworks that enable the creation of robust ocean forecasting services and enhance existing ones through shared architectures.
- Promoting interoperability and integration into digital twin platforms, in close collaboration with the Digital Twins of the Ocean Programme DITTO.
- Advocating for advancements in ocean forecasting science, particularly the adoption of AI techniques, in close partnership with key stakeholders.

Development of specific interoperability solutions and frameworks across the core components of the marine knowledge chain from upstream observations to downstream services (e.g. framework for observations/data for forecasting readiness level) will help to foster a strong interconnection between the observing-data-prediction components of the digital ecosystem as required by the Decade Data and Information Strategy.

We call upon the OceanPrediction DCC to work together with its group of regional/technical experts, the Expert Team of Operational Ocean Forecasting Systems (ETOOFS), and all relevant key Decade Actions to spearhead this transformative effort. By addressing current deficiencies, breaking down silos, and streamlining access to ocean forecasting techniques and results worldwide, we can collectively enhance our understanding and stewardship of the ocean.

(iii) Global Digital Atlas of the Ocean

We identify the need for an online user-friendly global Digital Atlas of the Ocean for both professional users, without hands-on data-handling expertise and a wider community of non-professional users.

The Atlas is intended to function at the interface between **Ocean Literacy** and **Data Management/Sharing** and links the ambitions of the Decade's Data and Information Strategy to wider society, acting as a 'community square' for sharing data-products developed by Decade actors and beyond. StoryMaps providing enhanced dynamic digital content to give meaning to the products and maps would strengthen the Atlas considerably. This will allow a diversity of users to be able to browse and interact with the products that are being created around the globe, including the priority base layers and local case studies developed as part of this Strategic Ambition. The envisaged Atlas should:

- Facilitate multi-lingual access.
- Be needs-driven and dynamic, going beyond static map layers.
- Reach the widest possible user group (e.g. with an API for providing access to a range of devices).
- Provide access to the priority global base layers with functionality to store at least some of these for offline use in land and sea areas where internet is sparsely available and/or

unreliable. This will allow derived products to include a common reference context for better understanding and interpretation.

- Support interrogation and interaction with the data-products and underlying data-resources from global layers to local products/data resources.
- Allow users to zoom into their specific area of interest and spotlight local areas.
- Be governed centrally, but with specific communities of practice responsible for maintaining their layers; layers that are not maintained should be removed.

It is important to note that proposing a new global Digital Atlas of the Ocean as key tangible outcome of the Decade, does not mean that there should be only one digital Atlas available to users encompassing everything that exists. Developers should still be able to harvest content from distributed, independent sources and construct atlases of the ocean or its parts to support user-friendly discovery and use of ocean data for specific regions, purposes and/or thematics. We recommend as part of the co-design and co-development process, to engage in a mapping exercise to inventorize existing digital ocean and coastal Atlases (collecting information on the technologies used, the content they provide and the purpose they serve), which could be leveraged and/or connected to the UN Decade Digital Atlas proposed as key outcome of the Decade.

The creation and development of the Atlas could notably build on expertise in the International Coastal Atlas Network (ICAN)[18] ICAN network and regional examples such as the European Atlas of the Seas[19] and Japan's Digital Marine Atlas'[20] whose technology could be repurposed thereby reducing the costs considerably. Private sector companies with capacity and expertise, among others related to developing tools and applications as well as story maps technology, should be approached to assist and contribute to bridge the gap from data/atlas to the end-users and broader public.

We call for ICAN and members of the global community of practice on digital coastal and marine atlases to further elaborate and define the functionality of the Atlas, cost it and recommend it as Decade Programme to develop it, exploring also existing infrastructures developed by the private sector[21] that could be adapted.

(iv) Marine Knowledge Exchange Mechanism

In addition to infrastructure facilitating sharing and use of ocean observations, data and data-products, we identify the need for a suite of tools, platforms and/or mechanisms which enable the sharing of other forms of ocean knowledge. These services would need to be inclusive, meaning open, accessible and easily useable by anyone who wishes to do so. Other forms of information and knowledge would include for example methodologies, recommended-practices, peer-reviewed publications, grey literature, software, social media, digital applications, videos, and other forms of non-typical knowledge outputs.

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[18] ICAN is a project of UNESCO IOC´s IODE Programme, and ICAN members seek to play a leadership role in forging international collaborations of value to the participating nations, thereby optimizing regional governance in coastal zone management and marine spatial planning. https://ican.iode.org/

[19] The European Atlas of the Seas provides information about Europe's marine environment, covering topics such as nature, tourism, security, energy, passenger transport, sea bottom, sea level rise, fish consumption, and much more.https://ec.europa.eu/maritimeaffairs/atlas/maritime_atlas

[20] https://www.msil.go.jp/msil/htm/main.html?Lang=1

[21] Members pointed to two companies who are particularly active with Google Earth and Microsoft planetary computers. https://www.techforwildlife.com/blog/2022/10/10/google-earth-engine-vs-the-microsoft-planetary-computer , https://wildlabs.net/discussion/google-earth-engine-vs-microsofts-planetary-computer-which-do-i-use.

This mechanism/infrastructure should:

- Facilitate different levels of access, reflecting the different users, from the wider public to professionals in the field.
- Facilitate multi-lingual access and input.
- Ensure curation, implement versioning and control of what constitutes a 'best-practice' is.

Examples of existing platforms, tools and systems that could be further developed and promoted include, the Ocean Best Practices System[22] which provides access to 'technological advances and community approaches for all ocean methods', OpenASFA[23] and AquaDocs[24], a joint open access repository of diverse knowledge products covering marine, coastal, estuarine, and freshwater environments.

We call upon IODE to foster and widely promote the use of platforms, mechanisms and tools actively used to store, share and exchange ocean information and knowledge beyond data and data products, in close collaboration with their hosting organizations and institutes;

(v) Enhanced Capacity Development and Training

To maximize engagement with the digital representation of the ocean (both contribution to, and use of), we identify the need for enhancing the facilities and resources available for Capacity Development and Training to improve data management practices and digital literacy. This needs to be tightly linked to the ambitions of, and efforts to address, Decade Challenges 9 and 10. This aspect was also highlighted as an important strategic objective (#5) in the Decade Data and Information Strategy (i.e. to Expand, empower, and mobilize global communities to advance and maintain the ocean digital ecosystem).

These facilities and opportunities should:

- Take account of language barriers.
- Provide a space to learn how to use the digital representation resources but also how to contribute to it, as well as to new uses of it.
- Be a two-way mechanism, to also collate user feedback on the digital representation(s) products and services, for owners/custodians to incorporate and improve future iterations of base-layers, data-products, services.
- Consider the need for the development of education systems to guide data utilization, leveraging initiatives which provide skill certification for example.
- Possible features could include:
  - Education and Advanced discovery modes[25]: educational version can be a series of pre-set themes with layers configure to a certain topic, while advance opens more choices;

[22] OceanPractices is a Decade programme to support all ocean stakeholders in securing, equitable sharing, and collectively advancing methods to manage our oceans sustainably. https://www.oceanbestpractices.org/
[23] OpenASFA, a system maintained by the FAO ASFA Secretariat and used by ASFA partners to create, store and share bibliographic records related to aquatic science and fisheries, with the option to deposit full text https://www.fao.org/asfa/en
[24] AquaDocs is the joint open access repository of the UNESCO/IOC International Oceanographic Data and Information Exchange (IODE) and the International Association of Aquatic and Marine Science Libraries and Information Centers (IAMSLIC) with support from the FAO Aquatic Sciences and Fisheries Abstracts. https://aquadocs.org/
[25] Example of recommended training site : https://www.sentinel-hub.com/explore/

- Case study page where users can either browse or submit analysis performed with the developed digital representation of the ocean;
- Blog/Social Media;
- Moderated forum;
- User guide and how-to videos;
- Teacher page: study materials and worksheets for teachers;[26]
- Virtual Research Environments / Virtual Labs. These can also be set-up for hands-on training on scientific tools and algorithms;
- Well accredited courses on MOOCS[27] platforms such as Udemy[28], of Coursera[29], UDACITY[30], edx[31];
- Citizen Science apps for data collection. (e.g. from indigenous fishermen[32]).

The Ocean Teacher Global Academy (OTGA)[33] could assist with capacity development and training. IOC is also launching an internship programme to build capacity in data-sharing. The Food and Agriculture Organization (FAO) e-learning Academy[34] which includes many online courses that include best practices and that includes science and data handling.

Combined with communication and outreach, these efforts should drive the ocean (science) community towards a culture where data information and knowledge sharing is automatic, integrated into normal practice - from the science community to wider society. This should result in a situation where the ocean community and broader public is aware of, has access to, contributes towards and ultimately uses the ocean digital ecosystem and digital representations of the ocean it provides.

We call for the Decade Capacity Building Facility, the Ocean Teacher Global Academy and network of experts of IODE, GOOS as well as the Decade Actions contributing in particular to Challenge 9 (i.e. Skills, knowledge and technology for all) to provide resources and training for increasing the data literacy of the Ocean Community to ensure meaningful contributions to the Decade's digital ecosystem.

[26] Example of initiative: https://www.worldwildlife.org/teaching-resources/toolkits
[27] https://www.mooc.org/
[28] https://www.udemy.com/
[29] https://www.coursera.org/
[30] https://www.udacity.com/
[31] https://www.edx.org/
[32] An example of an App developed by an ECOP to collect data from indigenous fishermen in Ghana was provided (Ruivo Demo project, Peter Teye Busumprah)
[33] https://www.oceanteacher.org/
[34] https://elearning.fao.org/

Annex 2. Processes and criteria for identification and selection of priority base layers and local case studies

As part of the Strategic Ambition setting for Challenge 8, we identify the need to elaborate transparent processes as well as guiding principles and criteria to (i) identify and select priority base layers and local case-studies for ingestion into the Digital Atlas; and (ii) co-design/co-develop the selected base layers.

(i) Process for the identification and selection of the priority societally relevant base layers and local case-studies:

Our ambition by 2030 is to have delivered at least one societally relevant global priority base layer (flagship data-product) and one local case study per Decade Challenge area. We recommend that the process of collecting suggestions and prioritization should draw on thematic Communities of Practice, Decade Actions and Working Groups focusing on addressing the other Challenges and that the selection process follows a series of developed criteria.

We identify the need for an independent Expert Group to oversee the consultation process with the various actors working to resolve the various decade challenges as part of the first-tier selection process of the base layers and identify the priority base layers and local case studies according to a set of to-be-developed criteria.

The criteria should include, amongst others the following:

(ii) For Priority Base Layers

- Societal relevance: in the context of the sustainable development goals and ambitions of the relevant challenge area as identified in the respective White Papers[35].
- Readiness level: in the sense of what is already being developed at regional level and can be built on.
- Compliance with FAIR and CARE principles: in terms of the adherence to or potential of the layer to meet FAIR and CARE principles.
- Potential to be used by the global community to make business cases to preserve and improve the ocean showing both an actual and a desired state, so the gap between the layers can serve to generate preservation or restoration Actions.
- Potential for long-term sustained funding to ensure that the base layer does not remain static, but is developed in an iterative, validated, and transparent process.
- Existence of an owner/custodian or community of practice working on developing the sought-after base layer via consensus. Where one does not exist, but the need for the base layer is

[35] https://oceandecade.org/vision-2030/

identified as a priority based on other criteria, then a call for an Action bringing together a consortium of data providers, implementers, and target users to co-develop it could be issued.

- Potential of the layer to leverage innovative and cost-effective observation technologies to address important data gaps.
- Recognition of best practice in current approaches at more local/regional level.
- The development and co-creation process will be crucial, and must be transparent, both in terms of the methodology and the underlying data, this invites and allows others to build on, improve and create new or better products.
- Serve as a public common reference context for other information, like OpenStreetMap and Google/Bing/Apple maps on land.

(iii) For Local Case Studies

- Priority is given to case studies located in SIDS and in coastal Least Developed Countries (LDCs), as LDCs are expected to have less institutional capacity to identify, collect, digitize, and share ocean data.
- Outreach establishes the opportunity and willingness of multiple stakeholders or their representatives to participate in co-creation of the case study. Special emphasis must be given to identifying and enabling the participation and empowerment of groups, especially marine resource-reliant groups, likely to have less voice at the national/regional level (e.g., Indigenous groups, small-scale fishers, stateless peoples, coastal populations living in poverty, women in the aforementioned groups and beyond). This approach will ground cases in local expertise and concerns. It will furthermore ensure that those who are less likely to have input into/access to/control over data and information that represents and affects them are empowered and included in case processes.
- A significant subset of the case study includes participation by stakeholders who have long-standing connections to and knowledge of marine and coastal resources that is grounded in ways of knowing other than Western science (i.e., Indigenous, local and traditional knowledge). These types of knowledge are likely to be more difficult to include into digital representations of the ocean, and participation by knowledge-holders is key to identifying gaps, barriers, and ways forward that are in line with CARE principles.
- A significant subset of the case study includes participation by stakeholders who hold relevant qualitative data grounded in Western scientific approaches. Although likely based on similar ontologies to quantitative data, qualitative data are anticipated to be more difficult to include in digital representations of the ocean and to cover different topics of interest, especially social phenomena.
- Ensure that local case studies include representatives from ecologically and socioeconomically significant ecosystems, such as upwelling ecosystems, crucial for sustaining food security and livelihoods of vulnerable small-scale fishers;
- The suite of case studies strives to represent a variety of ecosystems, as well as uses of, pressures on, and benefits derived from oceans and coasts, to best reflect the diversity of environments and experiences included under the umbrella of a global representation of the ocean.

The suite of case studies strives to represent a variety of conditions and challenges regarding existing data availability, to best reflect extant diversity in this area.

(iv) Process for co-design/co-development of the selected base layers

Building priority base layers implies a group or consortium consisting of all stakeholders including end-users for co-designing and co-developing the layers. This process is as important as the final product, to ensure transparency and agreement on what constitutes the best approach/methodology, what data (and sources) are incorporated, and to mitigate strategic and vested interests in the data and data-products. In some cases, a Decade Action bringing together a group of actors might already be working on developing the base layer (e.g. seafloor map as key deliverable of the Seabed 2030 initiative), while in other cases, data providers, developers, and users in need of a data product might still need to be brought together. This process of identifying essential target data products by 2030 may provide an incentive and clear objective to bring these actors together.

Ideally, the process for selecting, co-designing, and co-developing selected base layers would entail a 'consensus' process with validation or endorsement by IOC or other representative body which would help creating a set of 'reference' base layers which underpin the digital representation of the ocean and development of digital applications by all.

We call for maintaining an Expert Group beyond the delivery of this White Paper, as an independent expert group to: (i) oversee the identification and selection of priority base-layers and local case studies for integration into the global Digital Atlas; (ii) act as custodians of the selected priority base layer co-design and co-development process, overseeing the development and implementation of the guiding principles by the communities of practice developing the selected data-layers as well as their ingestion into the Atlas; and (iii) oversee the progress made overall to achieving the ambition targets of Challenge 8, using the set milestones and KPIs (see Section 4).

Annex 3: List of potential global data layers and case studies

Annex 3.1. Initial ideas for priority base layers with links to examples

CHALLENGE AREAS	MILESTONES ON THE ROAD TO SUCCESS
1. **Understand and Beat Pollution**	– Beach litter, microplastic distribution (link to the proposed global plastics treaty.) – Nutrient outflow – Ghost gear (source: global treaty, global ghost gear initiative, ...) – Spatial awareness layer that uses currents to show where pollution ends-up https://theoceancleanup.com/plastic-tracker/ – Layers on the concentration, distribution, speciation, sources, and thresholds (including proxy species) of key & emerging contaminants & their potential impacts (use Challenge 1 WP priority pollutants as reference). – One or more data layers with key drivers of priority pollutants; top pollution sources (paint, fishing gear, tourism) and collect the relevant data sources to track and beat them. – Consider layer(s) with information on habitat assessments: nutrients are often taken up quickly or have temporal distribution, thus it cannot be measured well. It is better to look at indirect effects, such as impact on ecosystems (i.e. benthic habitats). This can be easily read by indicator species or shifts in habitats as it shows an average exposure of the region.
2. **Protect and restore ecosystems and biodiversity**	– Consider global and regional marine life / coastal habitat layers including biodiversity, species distributions with some temporal resolution (climatological seasons if possible) and at a spatial resolution useful for the management of uses, modelled forecasts of species distribution, MPA siting and temporal boundaries/sunsetting, etc. – Marine Protected Areas and biodiversity hotspots – Vulnerable marine ecosystems (VME database https://www.fao.org/in-action/vulnerable-marine-ecosystems/vme-database/en/vme.html) – Consider adding a layer of ecosystem health: no protection nor restoration can take place without this information. It will also create clarity and action plans to many stakeholders. – Global layer of an inventory of preservation or restoration Actions that are ongoing to make our 1 Ocean equitable and sustainable. (See as an example the African Ushahidi platform https://www.ushahidi.com/) – Deep sea habitats (in areas identified for deep sea mining and elsewhere) – Showcase the great examples of restoration successes – Consider FAO sources

3. **Sustainably Nourish the Global Population**	– A global map of local ocean activities such as artisanal fishing to put coastal communities on the map, or aquaculture based on cages or coastal pond farming systems. Data does not exist but can be observed in high-resolution satellite imagery and modelled – Fish catch, aquaculture production (volume and value) - source: FAO – GlobalTuna georeferenced catches by 5-degree square - Source: FAO – FIRMS (annually updated by the 5 tuna RFMOs https://www.fao.org/fishery/en/collection/firms-tuna-atlas) – A global map of aquatic animal catches (by FAO major area and by countries, also available in certain areas by sub-areas). – A global map of status of fishery stocks (at species-genus-family granularity level, by FAO major area and at higher resolution fish stock by fish stock where assessment data has been made public – A global map of marine/brackish water aquatic animals aquaculture production by FAO major area and by countries – Global Fishing Watch data layer – Consider adding a layer of aquaculture and ecosystem health status. Aquaculture is seen as solution to feed growing population in many places of the world however it is highly destructive to marine habitats. Solution to the pollution aspects can only be implemented when the impact is illustrated.
4. **Sustainable Blue Economy**	– One common basic priority background layer available for all sectors and for myriad Digital Twins to place them in context (Example of the Swisstopo app https://www.swisstopo.admin.ch/) . Maritime companies would pay a significant license fee to have such a reference base map at their disposal: Electronic Nautical Charts that adhere to UN IMO standards. For example, an openoceanmap based on https://map.openseamap.org/ – Resource use, sand and gravel extraction, minerals extraction, kw/hours produced, goods transported,...). – Priority datasets (those that are required for/enable MSP/SOP) – Wind farm locations
5. **Ocean-Climate Nexus**	– Blue Carbon (source: e.g. blue carbon initiative) – Climate related pressures and changes (?) – Consider adding a data layer marking potential habitats with a great potential to remove CO2 out of the active carbon cycle. – Maps that capture different aspects of climate risks/changes, e.g. how water levels scenarios impact low lying areas, changing ocean condition (temperature etc.), increased damage from storms, ecosystem changes etc. Example: https://www.smhi.se/en/research/research-departments/oceanography/climemarine-effects-of-climate-change-into-marine-spatial-planning-1.150668 (also relevant to CH6)
6. **Coastal Resilience**	– Merged topography and bathymetry data set – global seafloor map (seabed 2030) – Human activities data sets e.g. fishers or fish farmers, economic indicators across sectors and their socio-economic interactions at high spatial-temporal resolution (For Fisheries, FAO maintains annual statistics of the number of fishers and aquaculture farmers by countries, by sex. Consider what employment statistics are maintained by OECD, by ILO, by WMO, etc.) – Sociodemographic data – Global Marine Spatial Planning (MSP) maps

7. Expand the Global Ocean Observing System	– Argo Positions – Ship Observation Team – Data Buoys – Ocean observatories – Research infrastructures – Ocean Shipping density maps (AIS)
8. Digital Representation	– Global seafloor map (seabed 2030) – Ocean Data-density layer to highlight gaps – Existing/developing Digital Twins (could be combined with local case studies - DTO's at local, regional (bay) level) MOI/Copernicus marine has contracted a global coastal bathymetry in 100m resolution to EOMAP and team. This is just one of multiple layers of global importance. You might want to add "Copernicus Marine services"
9. Skills, knowledge and technology for all	– One common priority background layer per challenge area, available to anyone with a smartphone in multilingual format – Global base layer of indigenous communities sharing data to global system – For this challenge area we note that the tools & services identified in the CH8 strategic vision, specifically the user-friendly Digital Atlas, Marine knowledge exchange mechanism, Global Data Help Desk and Capacity Building & training facility will be more relevant than specific base layers
10. Change humanity's relationship with the ocean	– Georeferenced SDG14 indicators – Traditional language translation of all selected priority base layers ingested – A storytelling layer on top of all priority base-layers explaining how they can contribute to the challenge area, e.g. https://theoceancleanup.com/plastic-tracker/ or https://ais-scrolly.netlify.app/ . – Global base layer of ocean literacy activities (some regional ocean literacy layers already exist) – For this challenge area we note that the tools & services identified in the CH8 strategic vision, specifically the user-friendly Digital Atlas, Marine knowledge exchange mechanism, Global Data Help Desk and Capacity Building & training facility (including games and training modules) will be more relevant than specific base layers.

Annex 3.2. Preliminary ideas as examples for proposed target local case studies to stress test the digital ecosystem, to identify challenges in the marine knowledge value chain (technical challenges, capacity limitations, ingestion facilities and DDAS usefulness)

LOCAL CASE STUDIES	SHORT DESCRIPTION	THEMATICS, DATA TYPES AND LAYERS HANDLED/PRODUCED	PROPOSED BY (CONTACT POINT)	RELEVANT CHALLENGE
Local fishermen in Ghana	- Data sharing by indigenous fisheries communities - Citizen science apps		- Peter Teye Busumprah	Challenge 3
Aquaculture in Africa *West Africa - Ghana, Nigeria, Niger, Benin, Cameroun)* *North Africa – Egypt, Morocco, Tunisia* *Southern Africa - South Africa, Namibia, Mozambique, Zambia, Zimbabwe* *East Africa - Tanzania, Kenya, Somalia, Uganda* *Central Africa -Cameroon* *SIDS - Cape Verde, Comoros, Madagascar, Seychelles.*	- Linkage of fish farmers to their resources through Digitalization - AO supports Nigeria on aquaculture tilapia, requires inventory of farming sites - FAO supports aquaculture censuses in Zambia and Zimbabwe. In Zambia, further proposals for community-based apps - FAO supports aquaculture censuses in Cameroon - Technology capacity building in Mariculture	georeferenced aquaculture data on aquaculture farms and farmer populations, and production levels georeferenced aquaculture data on aquaculture farms and farmer populations, and production levels georeferenced aquaculture data on aquaculture farms and farmer populations, and production levels	Peter Teye Busumprah Marc Taconet Marc Taconet Marc Taconet Peter Teye Busumprah	Challenge 3
Select from local pilot studies in development by Coast Predict Programme's GlobalCoast	Under the CoastPredict Programme, GlobalCoast is establishming a series of Pilot Sites across up to 20 diverse Regions of the Global Coastal Ocean. These are diverse in nature and some might fit well	Diverse	GlobalCoast / Coastpredict	Challenge 6

	to become local use cases to feature in the digital online Atlas as proposed in this White Paper for Challenge 8. A screening and selection process would be required.			
Aquaculture in the Caribbean (CARICOM)	FAO and CRFM collaborate on development and maintenance of an Inventory of aquaculture stakeholders (registry) and sharing of aquaculture related science (library) in Caribbean Island states. Digital Aquaculture registry and Library for CARICOM | Western Central Atlantic Fishery Commission (WECAFC) | Food and Agriculture Organization of the United Nations (fao.org)	A registry of aquaculture farms, practitioners (technicians/expertise) and institutions in the CARICOM region A digital library for aquaculture research publications concerning the CARICOM region managed on OpenASFA	Marc Taconet	
Scientist and Researchers in West Africa	This project features the integration of low-cost internet of things devices using effectors and sensors to measure, record and transmit marine environment variables. Sample parameters in scope: Temperature, Dissolved CO2 dioxide, pH, salinity, alkalinity, Nitrate, wave speed and drn, and turbidity. The data parameters are leveraged towards Oceanographic environment intelligence.		Peter Teye Busumprah	Challenge 7
Fishers in Comoros	The project is designed to assess the impact of Climate change on the socioeconomics of the fishers and the economy of the Country.	The project will require climate change impact data and socio-economics data for fishers.	Kamal Thabiti	Challenge 3

Fishing activity density in selected regions (e.g. NE or NW Atlantic where bias to such map is lesser)	Processing of AIS data. Potential to address AIS bias with complementary Navigation radar detector for monitoring all vessels equipped with radars	Various levels of fishing activity indicators (from presence/absence to number of hours fished for a given fishing gear) depending on coverage, quality and models	Marc Taconet	Challenge 3
Geo-referenced inventory of fisheries (artisanal and industrial) in 6 countries of the Gulf of Guinea in 8 countries of the Gulf in 11 countries of the Caribbean	About 40 fisheries are inventoried and status and trends information maintained by the Fisheries Committee for the West Central Gulf of Guinea (FCWC) as part of the FIRMS partnership. e.g. https://firms.fao.org/firms/fishery/1056/en same with 109 fisheries under the Commission on Fisheries (RECOFI) e.g. https://firms.fao.org/firms/fishery/1083/en same with 34 fisheries under the Western Central Atlantic Fisheries Commission (WECAFC) e.g. https://firms.fao.org/firms/fishery/907/en	Catch, effort, management measures by fishing unit. Qualitative and quantitative information on fisheries georeferencing of these fisheries (API services) materialized e.g. in WECAFIS (for Caribbean) https://www.fao.org/wecafc/data/wecafis/en/ (similar in the making for RECOFI and FCWC)	Marc Taconet	Challenge 3
Science on fishery sustainability in Southeast Asia **Science on marine fisheries in West Africa**	Recent ASFA Collections of Grey literature and datasets on fishery sustainability science in support to SDG14.4.1	Recent ASFA collection on SDG14.4.1 in 4 South East Asian countries (Philippines, Cambodia, Indonesia, Malaysia) Recent ASFA collection on fishery science in West Africa	Marc Taconet	Challenge 3
Local / indigenous knowledge relating to small scale fishermen	There is willingness by ASFA partner in the Philippines to test AI - Natural language processing on corpus of grey literature knowledge, which could be local knowledge captured by local universities		Marc Taconet	Challenge 3

Annex 4. Priority data needs across the Decade Challenges

Across the Ocean Decade Challenges, there's a pressing need to address a range of priority data gaps for different data types in terms of both resolution, geographic and temporal coverage. In first instance this should be addressed by making the vast amounts of already existing data more findable, accessible, interoperable, and reusable (FAIR). In addition, there is an urgent need to expand and enhance global ocean observation capabilities with cost-effective, innovative technologies and autonomous systems, alongside the need for comprehensive training programs to improve data literacy and management. There's also a crucial demand for identifying societally relevant datasets, prioritizing under-observed regions, and establishing coordinated databases that adhere to FAIR principles. These observations emphasise the importance of an integrated, collaborative approach that leverages technological advancements and global partnerships to make ocean science data more accessible and actionable, highlighting the interconnectedness of data needs across challenges and the imperative for cross-disciplinary efforts to bridge knowledge gaps and enhance the impact and sustainability of investments in ocean observations.

General observations and recommendations regarding priority data needs across the Decade Challenges

For many of the Challenge areas, while there are certainly still many gaps both in terms of resolution, geographic and temporal coverage and types of data, it is recognized that there is a lot of relevant data existing already, but challenges are often linked to this data not being easily findable, accessible, interoperable and (re-)useable (FAIR). Useful datasets are often incomplete, scattered across different local, national or thematic databases, or not shared at all. Other trends and requirements emerge such as the need to develop cost-effective strategies and technology innovations to advance sensors, data capture and sharing platforms as well as the need to enhance partnerships, capacity building, and knowledge integration across the ocean observing value chain. Emerging from the different white papers, it is clear that there is interconnectivity of data needs across the challenges, which highlights the importance of cross-disciplinary and collaborative efforts to address the data and knowledge gaps in ocean science.

Key trends concerning priority data needs across different Ocean Decade Challenges include in particular:

- There's a clear priority for expanding and enhancing global ocean observation capabilities, including the development of autonomous and low-cost monitoring systems, and improving the translation of data into accessible and usable products for a wide range of users, from scientists to policymakers. This encompasses the need for sustainable, interoperable, and standardized near-real-time data, as well as tools and services for easily accessing and sharing this data.
- There is a recognized need to train individuals across various levels of data literacy to create, manage, and use data efficiently and effectively. This involves changing the culture around data sharing, developing local technical and scientific expertise, and ensuring community buy-in for sustainable observing systems as well as long term data repositories. Training programs should not only cover data collection and analysis but also promote innovation in data processing and synthesis, as well as embrace cutting-edge technologies for both in-situ and automated data acquisition.
- The identification of societally relevant datasets and the prioritization of areas, pressures, pollutants, and under-observed regions are essential. Long-term datasets are crucial for

identifying baseline conditions, understanding temporal trends, and evaluating the effectiveness of regulatory actions.

- Coordinated global, regional, and national databases adhering to FAIR (Findable, Accessible, Interoperable, and Reusable) principles are needed to ensure data consistency and comparability.

The observed trends reveal a need for an integrated approach, taking advantage of technological advances, global collaboration and partnerships, while ensuring the data and tools developed are accessible and relevant to a broad spectrum of users. This requires coordinated efforts to build capacity, innovations in technology and data management, and actively engage all stakeholders in co-design and co-delivery of digital ocean solutions across the Ocean Decade and beyond.

Specific priority data needs identified by the different Ocean Decade Challenge Working Groups, based on cross-working group interactions and the information extracted from the White Papers:

Challenge 1: Understand and beat marine pollution

Expanding the following data collection and analysis efforts will be crucial for creating effective policies and actions to reduce marine pollution and its impacts on marine ecosystems and human health:

- Address data gaps related to the sources, impacts, and heavily contaminated areas of priority pollutants such as POPs, PFAAs, and Hg.
- Implement representative sentinel sites worldwide for long-term studies to evaluate temporal trends and the effectiveness of control and remediation actions.
- Connect datasets from across the land-sea interface, developing models covering land-sea interactions.
- Compile data into standardized and interoperable regional and global databases to reduce fragmented and scattered datasets and to facilitate sharing and better decision-making.

In addition, further priorities include:

- Detailed data on ocean currents, sediment transport, and biochemical processes to improve our understanding of the transport mechanisms and environmental fate of pollutants.
- Data on the effects of pollutants on marine biodiversity, including sub-lethal impacts and bioaccumulation across trophic levels, to better understand ecosystem health implications.
- Quantifying the socio-economic impacts of marine pollution on fisheries, tourism, and coastal communities to inform mitigation and compensation strategies.
- Identifying and monitoring emerging contaminants, such as microplastics, pharmaceuticals, and nanomaterials, which are not yet fully understood or regulated.
- Data on the effectiveness of pollution control measures, waste management practices, and remediation technologies in reducing marine pollution loads.
- Engaging communities in data collection and sharing local observations to enhance the spatial and temporal coverage of pollution monitoring efforts.

Challenge 2: Protect and restore ecosystems and biodiversity

The following data needs are considered critical for effective ecosystem and biodiversity conservation, enabling targeted actions for restoration and protection, and informing sustainable management policies:

- Comprehensive Habitat Mapping is essential for understanding ecosystem extents, conditions, and changes over time. This includes detailed mapping of coral reefs, mangroves, seagrasses, and other vital habitats.
- Establishing baselines and continuous monitoring of biodiversity across different marine ecosystems to track changes, threats, and conservation successes.
- Collecting and analysing data on human impacts, such as fishing pressure, pollution, and climate change effects, to understand and mitigate negative influences on marine biodiversity.
- Data on the genetic diversity within species, which is crucial for conservation planning and assessing resilience to environmental changes.
- Development of efficient tools for submitting and describing data; automation of metadata compilation.
- Training and motivating the next generation of data literate taxonomic experts.
- Development of interoperable and accessible databases and platforms that integrate ecological, biological, and human activity data for comprehensive ecosystem assessments.

Challenge 3: Sustainably feed the global population

- Availability of detailed digital representations of knowledge and data is critical to effective governance and management of aquatic food systems; this is especially important to address the needs of SSFA. There are currently extensive representations of aquatic food systems, but these are usually limited to ecological dimensions of the system and location-specific (with important regional gaps).
- Focus on infrastructure, including data infrastructure (e.g. storage, delivery, protocols for data sharing, inexpensive data collection and visualization methods and platforms), institutional infrastructure (especially in the Global South), and technical infrastructure (e.g. supply chain infrastructure for SSFA).
- Improve data on specific issues such as nutrition, biosecurity/health, bycatch data, human health (connecting to nutrition).
- Address lack of connectivity between components of food systems (land sea interactions).
- Strengthen and expand training programs for data collection, analysis, and promoting innovation in data processing and synthesis.
- Develop local technical and scientific expertise to handle different observing data streams and models for national fisheries, tourism, ocean health, and other blue economy resources.

Challenge 4: Develop a sustainable and equitable ocean economy

- Identify and use priority datasets and establish information and data frameworks, such as for comprehensive ocean accounts, for sustainable ocean management.
- Ocean accounts organize social, economic and environmental data and information to enable coherent planning of, and measurement of progress towards, the sustainable and equitable development of the ocean, promoting transparency, accountability, and sound decision-making.
- In general, socio-economic data is still largely missing or scattered.
- Encourage stakeholder and rightsholder involvement in data-related initiatives (data capture and knowledge co-production) and governance processes to ensure inclusive decision-making.

- Focus on comprehensive and up-to-date data on both human activities and state of the environment supporting informed and equitable decision-making.
- Downscaled datasets tailored to fit the specific needs of SIDS.
- Develop and maintain accessible, up-to-date, and reliable datasets to support sustainable ocean management.

Challenge 5: Unlock ocean-based solutions to climate change

- Unlock or generate priority datasets including high quality, comprehensive and accessible biodiversity, and carbonate system measurements for marine Carbon Dioxide Removal (mCDR) activities and other ocean-based solutions.
- Develop infrastructure for data generation, sharing, and capacity building, including cloud infrastructure and platforms measuring ocean carbon.
- Observations of physical, biogeochemical, and biological variables (via GOOS, GCOS, ...) to improve predictive capability of ocean, climate and weather forecasts.
- Address computational infrastructure challenges for demanding ocean and coastal models, and a foster global collaboration in data sharing and model development.

Challenge 6: Safe Ocean - Increase community resilience to ocean hazards

- Utilize a worldwide exchange of in-situ and space-based observation data for early warning systems.
- Downscale climate scenarios to the coast as a high priority dataset for adaptation planning.
- Risk assessment and management of ocean hazards requires a complex set of data from satellite, in situ platforms and numerical models. Key priority datasets are provided in annex 3 of WP6 including following data types: meteorological data; seismic and geophysical data; hydrological data; oceanographic data; human activities data; seabed habitat data; bathymetry, terrain, and geological data; climate downscaled scenarios; and human health data.

Challenge 7: Sustainably expanding the global ocean observing system

The following priorities are highlighted to advance the global ocean observing system, ensuring the delivery of accessible, timely, and actionable data and information to all users:

- Sustain observation of Essential Ocean Variables (EOVs) and address capability gaps in coverage and accuracy.
- Innovate data and information services to meet diverse user needs and challenges of Big Data.
- Expand observation capabilities to critical under-observed regions and assist developing nations in implementing observing as required. Coordination and integration of observations are essential for accurately predicting climate, forecasting weather, managing ocean health, marine biodiversity, food security, and informing mitigation and adaptation responses.
- Transform observation data into accessible and usable products for non-experts. This involves integrating data across various systems and platforms to create nimble products that are transformative, actionable, accessible, and suitable for specific users.
- Developing pathways to unlock existing but unavailable data, making it FAIR (Findable, Accessible, Interoperable, Reusable), and providing platforms for its storage.

- Development of more cost-effective technologies that cater to a range of users. Lowering technology barriers is crucial to ensure equitable access to observing assets and the smart management of these assets.
- Application of AI/ML tools to provide user-ready information from integrated observations, thereby democratizing access and use.

Challenge 9: Skills, knowledge and technology for all

- Enhance global access to technology and improve the availability of open-access platforms for ocean data, ensuring interoperability and ease of sharing across different users of the ocean.
- Establish policies that promote open access to ocean data and information, along with the development of standardized data formats to facilitate interoperability, sharing, and ethical data governance.
- Strengthen training programs focused on data collection, analysis, and processing, and promote the sharing of analytical tools and software to enable effective use of ocean data across diverse global communities.

Challenge 10: Restoring Society's Relationship with the Ocean

Success will partially depend on the generation, sharing, and use of the following priority datasets:

- human-ocean connection/human-ocean values dataset(s);
- pro-ocean behavior-change methodologies, case studies, and effective practices;
- impact mapping of regional and global ocean literacy key initiatives; and
- ocean culture mapping that includes a global body of evidence (contextual, local knowledge) that demonstrates and supports cultural engagement as an enabler of ocean-human health.

Beyond the specific data requirements associated with the 10 Decade Challenges, notable priority data and information requirements highlighted includes (i) information on marine governance frameworks, policies, and international agreements to promote transparency and accountability in ocean management; and (ii) data on stakeholder involvement in ocean governance processes, including mechanisms for inclusive decision-making and conflict resolution.

Annex 5. Other potential Progress Indicators for Challenge 8 Expected Outcomes

The below table/list of additional progress indicators that could be considered for tracking progress toward the main expected outcomes of Challenge 8 and achieve its strategic ambition is based on a broad list of potential indicators developed by the Decade Coordination Unit (DCU), selected, adapted and where possible tailored to be specific to WG8. These should be Specific, Measurable, Achievable, Relevant and Time-bound (SMART).

EXPECTED OUTCOME	INDICATORS RELEVANT TO WORKING GROUP 8
Outcome 1: Enhanced Ocean Data Accessibility and Availability Increased availability and accessibility of ocean data, including the streamlining of data-sharing platforms, standardized data formats, and open access policies.	Indicator 1.1: Percentage of relevant data made accessible (i) per selected priority base layer and (ii) per local case study at specific time intervals. The proportion of ocean data that is made available to create priority base layers. It can be measured by calculating the percentage of relevant data sets that are publicly accessible, considering factors such as data completeness, timeliness, and data quality. Indicator 1.2: Level of data interoperability achieved (i) per selected priority base layers and (ii) per local use case, differentiating between the data sources and the data products. The extent to which different data sources and formats are harmonized and interoperable. It can be measured by evaluating the adoption of standardized data formats, metadata standards, and data integration protocols across different data providers. The indicator can also consider the ease of data integration and data exchange between different platforms or systems. Indicator 1.3: Adoption of open access policies by Decade Actions. The extent to which open access policies are implemented to promote data sharing and reuse. It can be measured by tracking the number of Actions, organizations and/or institutions that have adopted open access policies for their ocean data. *Remarks:* – *Could consider categories - types of data/ topics/ geographic extent (horizontal and vertical), temporal coverage, thematic coverage.* – *Gaps identified - spatial/temporal/interoperability gaps.* – *On interoperability the DCO for Ocean Data Sharing is tasked to monitor the extent to which Decade Actions are adopting standards and have interlocuters with the Actions so this could be tracked.* – *On interoperability - differentiate the data sources from the products. Are the sources open and available?* – *Level of openness - open for any use/ open access policy. This is something that the DCO can track/ e.g. number of policies adopted.* *The Ocean Data and Information System dashboard should be able to provide meaningful information as to the evolution of number of references,*

	sources, data and products made discoverable and ultimately accessible, but does not show what isn't there
Outcome 2: Advancement in Ocean Knowledge Sharing Increased the generation and sharing of scientific knowledge and information related to the UN Ocean Decade Challenges.	Indicator 2.1: Number of research publications. Quantity of scientific research publications related to (i) all Ocean Decade Challenges; and (ii) Challenge 8. It can be tracked by counting the number of peer-reviewed journal articles, conference papers, and reports that contribute new knowledge or insights to the field. For (ii) the number of research publications related specifically to new Challenge 8 outputs of Strategic Ambition, i.e. creation of consensus base layers, local case studies, Global Digital Atlas etc. [criteria/terms to be specified]. Remarks: as for the other indicators: who tracks and how to actually define, could be any publication related to ocean data? Indicator 2.2: Number of knowledge products developed associated to creation of selected priority base layers and local case studies, and new tools and services created as part of Challenge 8 Strategic Ambition. Production of knowledge products such as reports, guidelines, toolkits, and manuals that provide practical information and guidance on addressing the challenges. It can be measured by counting the number of knowledge products developed and made available to stakeholders. Indicator 2.3: Number of best practices identified and shared associated to creation of priority base layers and local case studies, and new tools and services created as part of Challenge 8 Strategic Ambition. Identifying and sharing best practices or successful case studies that demonstrate effective approaches to addressing the challenge. It can be measured by tracking the number of documented best practices, success stories, or lessons learned that are shared with stakeholders. Indicator 2.4: Level of stakeholder engagement in knowledge sharing activities. Level of engagement and participation of stakeholders in knowledge sharing activities, such as workshops, conferences, webinars, and online platforms. It can be measured by tracking the number of participants, the diversity of stakeholder groups involved, and the feedback received from participants regarding the usefulness and relevance of the knowledge shared. *Alternatively, or complementary: Indicator 2.4b: Level of stakeholder engagement in knowledge sharing activities: Number of times priority base layers and/or data/products from local case studies are accessed or downloaded, measured by location, language and stakeholder group (if possible, to track/ask)* *Level of stakeholder engagement in local case studies: willingness of local communities to be involved in case studies. Metrics developed bottom-up, to assess inclusiveness of the process (communication, platforms to engage, feedback-incorporated)*

Outcome 3: Building Capacity for Ocean Decade Challenges Increased the capacity of individuals, institutions, and communities to effectively address the UN Ocean Decade Challenges.	Indicator 3.1: Number of capacity building initiatives [to improve digital literacy and addressing challenge 8]. Quantity of initiatives or programs specifically designed to build capacity in addressing the challenge. It can be tracked by counting the number of capacity-building initiatives, workshops, training programs, and educational activities implemented. This could be related specifically to proposed capacity-building mechanism) Indicator 3.2: Number of participants trained [to improve digital literacy and addressing challenge 8]. Reach and impact of capacity building initiatives by measuring the number of individuals who have participated in training programs or capacity building activities. It can be measured by tracking the number of participants enrolled, trained, or certified through these initiatives. Indicator 3.3: Level of institutional partnerships established in consortia creating selected priority base layers and local case studies. Establishment of partnerships and collaborations between different institutions, organizations, and stakeholders to facilitate capacity development. It can be measured by tracking the number of formal partnerships, memoranda of understanding (MoUs), or collaborative agreements established. Indicator 3.4: Assessment of skills and knowledge improvement. Perception of individuals or organizations regarding their skills and knowledge improvement after participating in capacity-building activities. It can be measured through self-assessment surveys or evaluations conducted before and after the training programs. Indicator 3.5 Number of trainings and uptake by downstream service providers and their outreach
Outcome 4: Sustainable Policy and Governance Implementation Increased development and implementation of policy and governance frameworks that support sustainable ocean management and address the UN Ocean Decade Challenges at hand.	Indicator 4.1: Adoption of relevant policies, legislation, and regulations. Extent to which relevant policies, legislation, and regulations have been adopted at the national or international level to address the challenges. It can be measured by tracking the number of policy documents, acts, laws, or regulations specifically targeting the challenge. *Remark: It is not clear how this could be measured and proven to have been related to Challange8, e.g. a new policy/regulation on the use/application of Digital Twins or AI in marine spatial planning, for example, could be considered within the scope but may have nothing to do with it.* Indicator 4.2: Integration into national and international agendas. Level of integration of the challenges into national and international agendas, strategies, or action plans. It can be assessed by examining the inclusion of the challenges in relevant policy documents, national development plans, or international frameworks and conventions. In theory this could be applicable to proposed priority base layers. Indicator 4.3: Stakeholder engagement in policy development. Engagement of stakeholders in the development of policies and governance frameworks related to the challenge. It can be measured by assessing the level of stakeholder participation, consultation processes, or the establishment of multi-stakeholder platforms. *Remark: Again,*

	how to prove that actually related to the outcomes of the strategic vision is not entirely clear. Indicator 4.4: Policy implementation and enforcement. Implementation and enforcement of policies and regulations related to the challenge. It can be measured by evaluating the extent to which policies are effectively implemented, monitored, and enforced. *Remark: Again, how to prove that actually related to the outcomes of the strategic vision is not entirely clear.*
Outcome 5: Inclusive Stakeholder Engagement Increased inclusive and meaningful stakeholder engagement and participation in addressing the UN Ocean Decade Challenges.	Indicator 5.1: Diversity of stakeholders involved. Diversity of stakeholders engaged in creating the selected priority base layers and local case studies. It can be measured by evaluating the representation of different stakeholder groups, such as government agencies, research institutions, civil society organizations, local communities, industry representatives, and indigenous groups. Indicator 5.2: Level of active participation. Level of active engagement and participation of stakeholders in activities related to the challenges. It can be assessed by tracking the number and quality of interactions, involvement in decision-making processes, and contributions to the development and implementation of initiatives. (similar to above?) Indicator 5.3: Incorporation of stakeholder perspectives. Extent to which stakeholder perspectives and contributions are incorporated into decision-making processes and the development of initiatives (including the selected priority base layers and local case studies. It can be measured by incorporating a feedback mechanism in the co-design process, evaluating the degree to which stakeholder inputs are integrated into the priority base layers, local case studies and tools and services, policy documents, action plans, or project designs. This indicator could include participatory modelling methodologies which allows stakeholders to co-develop digital twins. It could also include engagement with downstream solutions. This indicator could also include cooperation with other initiatives (national to global scale, such as Seabed2030, Copernicus Marine, Emodnet, NOAA's observation system, etc.)
Outcome 6: Societal and Environmental Impact *Increased positive societal and environmental impacts.* *[maybe too indirectly and less relevant for this challenge]*	Indicator 6.1: Ecosystem health. Improvement in the health and integrity of the ecosystems affected by the challenge. It can be assessed by tracking indicators such as biodiversity indices, water quality parameters, habitat restoration, and the recovery of key species. *Remarks:* - *Since CH8 is related to the entire ocean and all data typologies, this would be hard to measure. Could be adapted to the extent to which the base layers/ local case studies have contributed to improved knowledge on the health and integrity of the ecosystems?* - *As ecosystem health is one of the key drivers for resource management and preserving livelihood, food security and natural carbon sinks, tracking indicators of for example habitat health and biodiversity over time will enable a clear picture for which areas*

	improve or degrade. This is instrumental for meaningful decision making and management. It would be good to stress the risk of the lack of comprehensive data available and therefore the outcome and indicator would best include a focus on increasing the breadth and depth of available data in this area. Indicator 6.2: Livelihood improvement. Positive impacts on livelihoods, particularly those of communities dependent on the ocean and its resources. It can be measured by indicators such as increased income, employment opportunities, and diversification of livelihood options. Transdisciplinary research including social and economics scientists will be necessary to measure this important indicator. *Remark: Not sure this can be measured as related to this Strategic Ambition in the proposed timeframe, unless related to new training?* Indicator 6.3: Resilience enhancement. Increased resilience of communities, ecosystems, and sectors to the impacts of the challenge. It can be assessed by indicators such as reduced vulnerability to climate change, improved adaptive capacity, and the implementation of risk reduction measures. *Remark: Again, not really something related to this challenge, specifically, but could instead measure the ability to measure resilience as a result of increased access to digital representation?* Indicator 6.4: Reduced vulnerability. Reduction in vulnerability of communities and ecosystems to the specific challenge. It can be measured by tracking indicators such as decreased exposure to hazards, improved preparedness, and enhanced coping mechanisms. *Remark: Again, not really something related to this challenge, specifically, but could instead measure the ability to measure resilience as a result of increased access to digital representation?* Indicator 6.4: Resource efficiency and sustainable practices. Adoption and promotion of resource-efficient and sustainable practices. It can be measured by evaluating factors such as energy consumption, water usage, waste management, greenhouse gas emissions, sustainable procurement practices, and the integration of environmental considerations into decision-making processes. *Remark: Again, not really something related to this challenge, specifically, but could instead measure the ability to measure resilience as a result of increased access to digital representation?*
Outcome 7: Increased Funding for Decade Actions Increased funding for the implementation of actions addressing the UN Ocean Decade Challenges	Indicator 7.1: Funding raised. Amount of funding secured for the implementation of Decade Actions addressing Challenge 8. It can be assessed by tracking the total financial and in-kind resources mobilized from various sources, including government funding, private sector investments, and philanthropic contributions. Indicator 7.2: Diversification of funding sources. Diversification of funding sources for addressing the challenge, (selected priority base layers, local case studies and tools and services). It can be measured by tracking the proportion of funding received from different sectors, such

	as government, private sector, civil society organizations, and international funding mechanisms. Indicator 7.3: Sustainable financial mechanisms. Establishment of sustainable financial mechanisms to support the long-term implementation of actions (priority base layers, local case studies and tools and services) (also beyond the timeframe of the Decade). It can be assessed by indicators such as the development of trust funds, endowments, public-private partnerships, or innovative financing mechanisms. Number of new trainings for stakeholders on how to access and apply to financial mechanisms (and number of attendees). Indicator 7.4: Leveraging of resources. Ability to leverage additional resources to support creation/development of priority base layers, local case studies and tools and services through partnerships and collaborations. It can be assessed by tracking indicators such as the value of co-financing arrangements, in-kind contributions from partners, and the mobilization of resources through leveraging networks and alliances.
Outcome 8: Diverse and Inclusive Decade Actions Increased diversity and inclusivity within actions of the UN Ocean Decade.	Indicator 8.1: New programmes and projects. Number of new programmes and projects initiated that focus on addressing underrepresented topics or geographical regions. This indicator measures the concrete actions taken to prioritize and address gaps in representation within the UN Ocean Decade. Indicator 8.2: Diverse allocation of resources. Percentage increase in the allocation of resources to Decade actions targeting underrepresented areas. This indicator tracks the shift in resource allocation to ensure that adequate funding, expertise, and technology are dedicated to initiatives focusing on underrepresented topics or regions. Indicator 8.3: Improved partnerships. Number of partnerships established with organizations and stakeholders from underrepresented regions to foster collaboration and knowledge exchange. This indicator measures the extent of collaboration and engagement with entities from underrepresented regions. Indicator 8.4: Stakeholder satisfaction and feedback. Measurement of stakeholder satisfaction and feedback on the implementation of programs and projects. It can involve conducting surveys or feedback mechanisms to gather stakeholders' perspectives on the relevance, efficiency, and outcomes of the initiatives.
Outcome 9. Advancement in Ocean Technology and Innovation Increased advancement in ocean technology, innovation, and infrastructure to support ocean research and management.	Indicator 9.1: Technological innovations implemented. Number of new technological innovations integrated into developing the Challenge 8 services and more broadly the development of the envisaged Digital Ecosystem, reflecting the progress in advancing technology within specific timeframes. Indicator 9.2: Research infrastructure enhancement. Percentage increase in research infrastructure investments dedicated to Challenge 8 related projects addressing the goals of this Strategic Ambition (e.g.

	proposed tools and services such as the Global Digital Atlas) demonstrating the commitment to improving the tools and facilities essential for ocean exploration and research. Indicator 9.3: Collaboration with tech industries. Number of collaborations established with technology industries and start-ups, fostering partnerships to develop innovative solutions and enhance the utilization of cutting-edge technology in ocean science in creation/development of Strategic Ambition goals. *General Remark: This outcome and indicators remain quite high-level. It would be useful to specify what kind of innovation is needed to meet the SDGs. For example, investment in technology that can automate ocean data collection and analysis, as we are currently still relying a lot on small scale initiatives.*
Outcome 10. Enhanced Utilization of Ocean Science and Knowledge Increased use of ocean science and knowledge for various purposes.	Indicator 10.1: Knowledge transfer events. Number of workshops, seminars, or training sessions conducted to disseminate ocean science knowledge among diverse stakeholders, demonstrating the efforts to enhance public awareness and understanding of ocean-related issues. The dissemination and knowledge-transfer through intermediate users providing downstream services (downstream service providers) has a great potential and allows for customized knowledge transfer in different languages and countries. So, the transfer and support of downstream can be a target which surely can have outreach to a broader end-user group (2 to 3rd end-user levels). Indicator 10.2: Increase in data utilization. Percentage increase in the utilization of available ocean data by research institutions, governmental bodies, and non-governmental organizations, indicating the growing reliance on existing data for scientific studies and decision-making. This could be done for example by building in a dashboard of base layers/ case studies. Indicator 10.3: Increase use of ocean science and knowledge for sustainable development. Percentage increase in the integration of priority base layers/local case studies/tools and or/related methodologies/best practices in sustainable development strategies, showcasing the influence of scientific knowledge on decision-making. Number of sustainable practices and technologies derived from ocean science, indicating tangible contributions to sustainable development goals. Indicator 10.4: Increased educational impact. Number of educational outreach programs conducted, demonstrating efforts to enhance public knowledge and appreciation of ocean science using developed base layers, tools and services. Number of educational institutions incorporating ocean science into their curricula, demonstrating the integration of ocean knowledge into formal education systems. Percentage increase in student participation in ocean science-related extracurricular activities, showcasing enhanced interest and engagement among the youth. Remark: we can leverage the ECOPs network to see what is already being done

United Nations Decade of Ocean Science for Sustainable Development (2021-2030)

Proclaimed in 2017 by the United Nations General Assembly, the UN Decade of Ocean Science for Sustainable Development(2021-2030), provides a convening framework to develop the scientific knowledge and partnerships needed to catalyse transformative ocean science solutions for sustainable development, connecting people and our ocean. The Ocean Decade is coordinated by UNESCO's Intergovernmental Oceanographic Commission (IOC).

Established during the Preparatory Phase and to continue throughout implementation until 2030, the IOC's Ocean Decade Series will provide key documentation about this global initiative and aims to serve as a primary resource for stakeholders seeking to consult,monitor and assess progress towards thevision and mission of the Ocean Decade.

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