



Evolving and Sustaining Ocean Best Practices to Enable Interoperability in the UN Decade of Ocean Science for Sustainable Development

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The UN Decade of Ocean Science for Sustainable Development (Ocean Decade) challenges marine science to better inform and stimulate social and economic development while conserving marine ecosystems. To achieve these objectives, we must make our diverse methodologies more comparable and interoperable, expanding global participation and foster capacity development in ocean science through a new and coherent approach to best practice development. We present perspectives on this issue gleaned from the ongoing development of the UNESCO Intergovernmental Oceanographic Commission (IOC) Ocean Best Practices System (OBPS). The OBPS is collaborating with individuals and programs around the world to transform the way ocean methodologies are managed, in strong alignment with the outcomes envisioned for the Ocean Decade. However, significant challenges remain, including: (1) the haphazard management of methodologies across their lifecycle, (2) the ambiguous endorsement of what is “best” and when and where one method may be applicable vs. another, and (3) the inconsistent access to methodological knowledge across disciplines and cultures. To help address these challenges, we recommend that sponsors and leaders in ocean science and education promote consistent documentation and convergence of methodologies to: create and improve context-dependent best

practices; incorporate contextualized best practices into Ocean Decade Actions; clarify who endorses which method and why; create a global network of complementary ocean practices systems; and ensure broader consistency and flexibility in international capacity development.

Keywords: UN Ocean Decade, interoperability, best practices, capacity development, methods, standards

INTRODUCTION

Access to information and knowledge about the ocean, at scales ranging from local to global and seconds to centuries is essential to address many of the United Nations (UN) Sustainable Development Goals (SDGs, UN Agenda, 2020). A UN Decade of Ocean Science for Sustainable Development 2021–2030 (Ocean Decade) was proclaimed in December 2017 and launched in 2021 to support “transformative ocean science solutions for sustainable development, connecting people and our ocean” (IOC, 2020a). The Ocean Decade identifies seven Outcomes (Table 1) and three Objectives in its Implementation Plan (IOC, 2020b).

Cooperation from local to global scales is needed to achieve the Ocean Decade’s Outcomes and Objectives. Thus, coordinating the ocean methodology – including guidelines, policies, standard specifications, and methods – that underpins cooperation is essential. In the *Call for Actions Guidance Note* (IOC, 2020c), the IOC encourages Ocean Decade programs “to address interoperability and to develop and use best practices in their work,” echoing previous calls (Speich et al., 2019; Ocean Frontiers Institute, 2020). Developing global consensus on how methods should interoperate and evolve into context-qualified best practices is still a major challenge for realizing the Ocean Decade’s ambitions.

In this article, we provide perspectives on (1) how methodology management systems (MMS) can work together to support the creation, review, distribution, and updating of best practices and other methodologies under the Ocean Decade and (2) how the co-creators of methods can better define best practices. As a key outcome, these activities will help Ocean Decade Actions generate transparent, traceable, comparable, and trusted data, information, and knowledge for science and society (Claudet et al., 2020). Co-developed ocean methodologies will be instrumental in bridging cultures of practice and deepening trust across diverse stakeholders and regions. Building this basis of transparency and trust will be central to integrating Ocean Decade Actions and reconciling their scientific outputs with management actions (Foster et al., 2017).

This Perspective explores why a transformational shift is needed in the way the ocean community handles methods and best practices and suggests a path forward. We orient our perspectives on the Ocean Decade’s initial Objectives and Outcomes, and draw from our experience of building the IOC Ocean Best Practices System (OBPS; Buttigieg et al., 2019; Pearlman et al., 2019) as well as our continued work to make the OBPS interoperate with other existing and emerging MMS solutions. We hope that this perspective will help creators and

managers of ocean practices align and co-create joint solutions with global reach and local relevance.

WHY WE NEED A TRANSFORMATIVE MOMENT FOR OCEAN PRACTICES

We summarize below our perspectives on six core challenges in ocean methodology creation, development, and management (C1–C6) which have motivated us to develop the OBPS, with the hope of inspiring related and interoperating activities in the wider ocean community.

C1: Ocean Practices Are Undervalued and Under-Incentivized

The vast majority of the ocean community does not maintain its methodological knowhow in open access, sustained, and secure archives. This is a prerequisite for Ocean Decade’s Implementation Plan; if we are not able to trace *how* the Outcomes and Objectives are met through Decade Actions, then building trust, supporting reproducibility, advancing and transferring capacities, and building a legacy beyond 2030 will all be severely inhibited.

This is particularly important for capacity development and retention within local communities; development hinges on the transfer of knowhow, and retention occurs if that knowhow is shaped into locally relevant best practices. Courses, summer schools or 1-week sessions that provide a one-time introduction to methods for a limited number of trainees are not enough; establishing sustained mentorship and professional contacts is needed for two-way evolution of ocean practice. Such networks do not exist on the scale needed by the Ocean Decade and even the documentation of training methods is lacking.

Despite their necessity, dedicated publishing of complete methods is undervalued and rarely rewarded through funding or scientific career advancement. Thus, vital methodological insight is often only available (often in highly condensed, supplementary, or unreviewed form) in academic publications, which are not always open access. Even when this content is present in journals dedicated to methods, it is unlikely that reviewers have replicated and/or tested the methods. Such factors contribute to the real or perceived reproducibility crisis in science (e.g., Baker, 2016) and barriers between scientists and other ocean practitioners (Pendleton et al., 2020). Further, the engineers, software developers, analysts, and staff conducting outreach, policy, logistics, and other activities essential to the scientific enterprise often have little incentive to share their essential knowhow with the broader community. The scientific value of

TABLE 1 | The UN Ocean Decade outcomes and how they can each be supported by systematic handling of methodological content (methods, standards, policies, etc.) and identification of best practices.

Ocean Decade outcome	Relationship to a coordinated ocean methodology and best practices system
1. A clean ocean where sources of pollution are identified and reduced or removed	Methodologies associated with a context-sensitive registry or <i>ad hoc</i> list of pollutants (physical, chemical, biological) can be rapidly identified and triaged for suitability for monitoring and remediation
2. A healthy and resilient ocean where marine ecosystems are understood, protected, restored, and managed.	Methodologies can be indexed and accessed by their association to environmental conservation/restoration policies, management plans, indicator and assessment guidelines, or intervention/response methods; official and unofficial perspectives on health, resilience, protection, and restoration may be efficiently compared and contrasted.
3. A productive ocean supporting sustainable food supply and a sustainable ocean economy.	Placement and cross-linkage of methodologies along well-defined and regionally sensitive economic and food-security-based value chains; linkage to regulatory guidelines as well as observations and models of regional productivity and biodiversity.
4. A predicted ocean where society understands and can respond to changing ocean conditions.	Methodologies used to develop models, coordinate ground truthing and assimilation, specify and account for uncertainties across the data lifecycle, improve predictions, evaluate forecasts, and launch responses are available in accessible terms to improve public understanding of how and why the ocean impacts their lives and livelihoods.
5. A safe ocean where life and livelihoods are protected from ocean-related hazards.	Methodologies indexed by socio-environmental setting and hazard type can be rapidly collated and compared to enhance hazard prediction, mitigation measures, rescue and recovery; methods to rapidly discover and collaboratively update methods on emerging and unfolding hazards are supported.
6. An accessible ocean with open and equitable access to data, information and technology and innovation.	Precise versions/variants of methodologies and inclusion of international metadata formats and relevant standards used to generate digital or hardware-based technologies, as well as those used to generate or process digital content, are persistently accessible and easily integrated into provenance records to promote transparency and reuse. Support of FAIR and CARE principles and effective integration of recognized methodologies and standards (e.g., ISO 19115/19139), providing a foundation for open and equitable access.
7. An inspiring and engaging ocean where society understands and values the ocean in relation to human wellbeing and sustainable development.	Methodology management systems provide engaging access to narratives and media explaining how diverse ways (i.e., methods, writ large) of interacting with the ocean can (1) reveal its incalculable value in promoting quality of life for individuals and societies and (2) promote or detract from a sustainable relationship with the ocean. In particular, systems should highlight citizen science and community-based observation methods.

publishing methodologies must join that of open data in gaining acceptance and funding as a first-order scientific output (NSF, 2014). Without more value placed on complete, open, replicated and community validated practices, we hamper ourselves while approaching far less ambitious initiatives than the Ocean Decade.

C2: Tracing the Methods That Create Ocean-Related Data, Information, and Knowledge Is Prohibitive

Currently, the marine science community cannot efficiently and unambiguously trace the methods it uses to generate, process, or otherwise handle its data, information, and knowledge. Such provenance is essential to building trust in, and assessing the accuracy of, ocean digital resources (Buck et al., 2019) and supporting realization of the FAIR (Wilkinson et al., 2016) and CARE principles (Carroll et al., 2020). With the inevitable and rapid evolution of marine observation technology over the next decade, we need to deeply integrate precise tracing of methodologies into the metadata associated with myriad sensors (Wang et al., 2019) and autonomous platforms (Whitt et al., 2020). Those constructing the Internet of Things are confronting this issue (e.g., Elkhodr and Alsinglawi, 2020), and it is only a question of time until we will be charged with co-managing the methodological histories linked to the Internet of Ocean Things.

Without a far greater capacity to integrate methodological provenance into metadata records, the marine community will struggle to generate data with clear, auditable provenance

which document known uncertainties (i.e., as a component of asset grade data; AGD¹) using rigorous security approaches and auditing tools. We believe that AGD will become a requirement for policy decisions, particularly in applications such as aquaculture and ecosystem management; however, our methodological management in marine science needs great improvement to successfully address such developments.

C3: Linguistic and Cultural Barriers to Discovering, Responsibly Using, and Co-developing Methodologies Are Still High

To achieve the geographic and culturally attuned coverage called for in the Ocean Decade, the ocean science community needs methodologies accessible in different languages, modalities (i.e., other than documents) and sourced from all regions including underrepresented regions and communities. This will drive an expansion of the technological capabilities used for enhanced discovery of methods in the OBPS and potentially in other MMS.

Currently, very few actors in marine science have the capacity to support multilingual and *trans-cultural interpretation* (rather than simple translation) or host content in other than textual form. We are thus more vulnerable to violations of trust or ethical norms when conducting research which impacts the multiple stakeholders of marine science (e.g., Carroll et al., 2020).

¹<https://www.contextlabs.com/posts/2019/10/9/assetgradedata>

While some MMS solutions (especially those in the UN information systems) are taking preparatory steps to host and index multilingual and non-textual content, our community is not currently able to collectively overcome these barriers. Local groups and indigenous nations and cultures – frequently highlighted in Ocean Decade narratives – are particularly vulnerable to this lack of capacity, as immense methodological knowledge is maintained in oral histories or artifacts.

C4: Methodology Archives and Management Systems Are Strongly Siloed and at Times Inaccessible

Thus far, we referenced the IOC OBPS as an example of marine MMS, but there are many other ocean-relevant methodology collections published in differing formats by, for example, the International Council for the Exploration of the Sea² (see also ICES, 2019), the World Meteorological Organization³, the National Ecological Observatory Network (NEON)⁴ and multiple research institutes around the world. Unfortunately, this immense pool of knowledge is typically not interoperable, coordinated, or effectively digitized. When collections are accessible online, ocean practitioners still cannot search across these resources without knowing they exist and using multiple portals with drastically different user experiences. Additionally, most MMS solutions have no functions to identify content that is of specific relevance to the Ocean Decade or the SDGs. The Ocean Decade will be plagued by disjointed practices if we cannot transform these silos into a federated (i.e., sharing aligned visions) and interoperable (i.e., using common standards) network for the Ocean Decade.

C5: The Concept of “Best Practice” Is Increasingly Necessary but Increasingly Ambiguous

In a “victim of its own success” scenario, the term “best practice” is heavily used, generally accepted as positive and desirable, and at risk of trivialization. Some developers of highly effective methods are hesitant to use the term while others use it prior to their practices being validated or evaluated. To prevent the valuable concept of “best practices” becoming nothing more than a buzzword, the community must develop better consensus on what constitutes a best practice, in what operational context, at what resourcing level, and for which community of practice. Further, we must be far more precise about the differences between *de jure* and *de facto* best practices as well as on what we mean with terms like “best practice” and “standard.”

In our work developing the OBPS and soliciting community feedback, we (informally) synthesized multiple community perspectives on what constitutes a “best practice.” Our current operational definition is:

A best practice is a methodology that has repeatedly produced superior results relative to other methodologies with the same

objective; to be fully elevated to a best practice, a promising method will have been adopted and employed by multiple organizations (Simpson et al., 2018; Pearlman et al., 2019).

This definition largely conforms with those in other fields (Abudi, 2011; Hora, 2017), and emphasizes repeated testing, cross-validation, and community update. However, this definition will certainly not be the only one socialized during the Ocean Decade as stakeholders – even within marine science – will insist on different emphases. For example, some may question whether adoption is necessary to be “best” rather than simply popular. Those working with quantitative and well-replicated data will likely emphasize the need for uncertainty estimation, while those working with human communities or endangered species will emphasize the ethical dimensions of ocean research. Further, through the OBPS workshop series (Simpson et al., 2020), we have encountered very different perspectives on how to gauge the maturity of a practice along dimensions (often ambiguously defined) of readiness, feasibility, and impact. As this diversity emerges, we must find a scalable and coherent way to manage these different criteria across and within communities. Otherwise, there is limited hope of achieving inclusive yet coherent methodological interoperability contributing to the Ocean Decade’s science-to-science and science-to-society interfaces.

C6: Inclusively Converging Methods Into Endorsed Best Practices Is Prohibitive

In an ideal operational scenario, the best practice for a given challenge would be (1) synthesized by converging content from as many relevant methodological sources as feasible; and then (2) reviewed, tested, and endorsed by a competent authority or community of practice. However, due to the lack of accessibility, effective indexing and discoverability, and the siloed stores of methodologies, the range of what is considered feasible is curtailed. Further, who endorses which method and why is often opaque to the broader community. As a result, the current way of converging and endorsing methods is likely to be too narrow to drive the transformative science called for during the Ocean Decade.

DISCUSSION: A PATH FORWARD – FROM CHALLENGES TO TRANSFORMATION

The Ocean Decade provides a unique opportunity to trigger an urgently needed transformation in how we value, develop, manage, and use ocean methodologies. We remain optimistic that such a transformation is within reach – the necessary technologies, expertise, and drive exist and the Ocean Decade can provide an the essential framework for global coordination. However, the Ocean Decade is no silver bullet. Just as the task of co-developing best practices falls on the community (Claudet et al., 2020), so do the co-creations of global solutions to collectively manage ocean practices during and after the Ocean Decade.

²<https://www.ices.dk/Science/publications/library/Pages/default.aspx>

³<https://public.wmo.int/en/resources/standards-technical-regulations>

⁴<https://www.neonscience.org/data-collection>

Based on the perspectives offered above, we recommend the following principles for those developing and managing ocean methodologies supporting the Ocean Decade's Objectives and Outcomes. We include cross-references to link these principles to the challenges we noted above (C1–C6). From such principles, we envision that schemes will emerge to help ocean communities (broadly defined) understand each other's priorities in contributing to the Ocean Decade.

For the Creators of Methods, Standard Specifications, Guidelines and Other Forms of Methodology Documentation

General guidelines for creators of methods have been provided in Hörstmann et al., 2020. This section provides further elaboration of the guidance provided in this reference.

1. **Consistency:** Standardized formats, style, consistent with the Ocean Decade's high-level guidance (IOC, 2020c) will promote communication and interoperation (C2, C4, C5).
2. **Completeness:** Reproducibility must be assured, especially in international and multi-disciplinary contexts. Thus, methodologies should be self-contained and allow reproducibility without ambiguity. In the Ocean Decade, completeness implies that the methodology provides a clear and concrete description of how its use contributes toward the Challenges and Objectives specified in the Implementation Plan. These aspects will help MMS developers promote improved linkages between and convergence of ocean practices (C1–4).
3. **Comprehensiveness:** Knowing how the application of a methodology may change when (1) deployed at local, regional, or global scales (as appropriate) and (2) when deployed in differing operational contexts (e.g., high/low capacity, impacting local communities, etc.) is essential. An exhaustive account is typically not feasible, but even modest efforts can greatly help discoverability and broader use, as well as the detection of opportunities for capacity exchange and development (C1, C3, C5, C6).
4. **Convergence:** Emphasize and expand efforts to incorporate or interoperate with competing/complementary methods. This will reflect a key transformative dynamic of the Ocean Decade, where competition transitions into collaboration and methodological innovation can be harnessed through convergence into context-qualified best practice recommendations. This will also be instrumental for building MMS interoperability (see below) and information systems with global scope but local precision (C2, C4, C6).
5. **Endorsement:** If applicable, methodology creators should explicitly and clearly identify whether, how, by whom and for what their work has been endorsed. As a prototype and example to the community, a structured process for endorsement has been developed in a partnership between OBPS and GOOS to clearly communicate what GOOS Expert Panels have identified as good or best practices (Hermes, 2020) (C1, C6).

For the Developers of Methodology Management Systems (MMS)

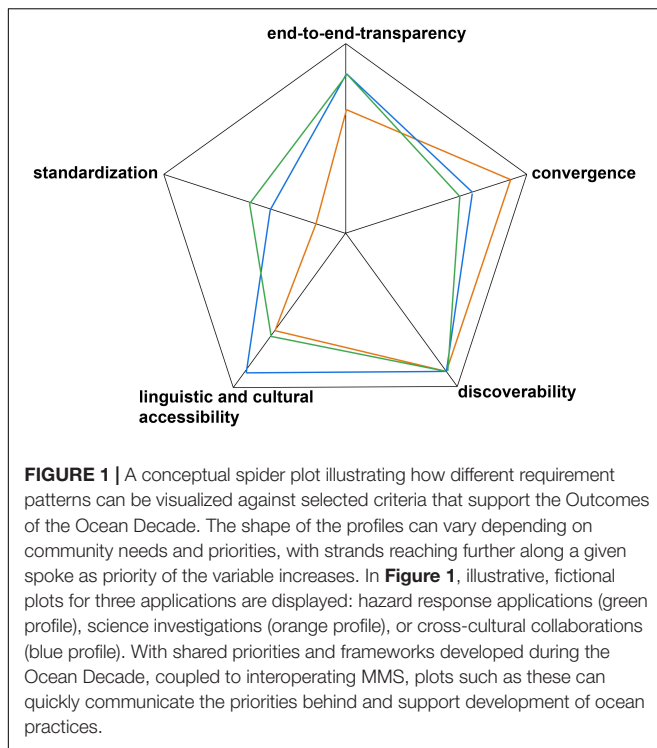
6. **Globalization:** MMS must factor in some degree of multi-lingual support and culturally attuned user experience to boost global inclusivity and forge new collaborations past linguistic and cultural barriers (C1, C3).
7. **Convergeability:** To complement convergence (see item 4), MMS should include mechanisms to detect related methods and feed these forward into a convergence workflow, working with the relevant method creators. Which methods converge in which operational context will be immensely informative in the development of contextualized best practices supporting evaluation and endorsement activities. Additionally, community fora⁵ and standardized metadata will be key to convergence (C2–4, C6).
8. **Endorsability:** To complement and support the endorsement efforts above (item 5), MMS should have mechanisms to support, record, and project onto the web (in human and machine-readable forms) who has endorsed what and why (C1, C4, C6).
9. **Networking:** No MMS should operate in isolation, especially not within Ocean Decade activities that seek to dissolve boundaries. Thus, systems handling ocean knowhow should leverage web-based interoperability technology and standards to function as a network of complementary systems. MMS should be able to search across all others in the network, accessing a collective methodological knowledge base through a local interface (C1–4).
10. **Portability:** We cannot assume that all stakeholders will have stable access to the Web – provision for exporting compendia of methods in compressed files and efficiently distribute them, should be a standard feature of Ocean Decade MMS (C4, C6).

For Funders, Policy Bodies, Directorates, and Advisory Boards of Ocean Science

11. **Incentivization:** Create the motivation and funding for scientists to more thoroughly document, validate and converge methods into best practices (C1).
12. **Impact:** Require that the societal value of a method is clearly defined, with concrete indicators of societal impact (C1, C5).
13. **Co-development:** Require that relevant communities outside of science are meaningfully engaged in the early co-design, validation, and endorsement of ocean methodology. This includes end users of the data and information derived from that method (C1, C5, C6).
14. **Empowerment:** Provide and advocate resources to meaningfully develop global capacity (e.g., through long-term mentoring and knowledge transfer) to expand the reach of promising methods or best practices.

There are many examples where communities have pursued one or more of these principles. These include the documentation

⁵E.g. see <https://forum.oceanbestpractices.org>



and convergence of methods for machine-learning using images taken in the field by the Marine Biodiversity Observation Network (MBON) Pole to Pole Americas project and now used by groups such as the Multi-Agency Rocky Intertidal Network⁶. NEON⁷ has developed and propagated extensive and systematic (complete, converged, and comprehensive) recording of standard operating procedures. Further, the development, refinement, and adoption of the U.S. IOOS QARTOD project's Manual for Real-Time Quality Control of High Frequency Radar Surface Current Data (IOOS, 2016) has improved consistency of field operations. In Australia, the Marine Sampling Field Manuals for Monitoring Australia's Marine Waters support the convergence and endorsement of method for national-scale monitoring and observing of Australia's marine environment while also connecting to global initiatives through the Ocean Best Practices System (Przeslawski et al., 2019). The ocean community is encouraged to join us in the collection of success stories which will be included in an OBPS compendium.

In conclusion, the enhanced management of methods and development of context-specific best practices are fundamental for the Ocean Decade. While basic scientific research continuously generates and evolves practices, there is an essential need to systematically identify, manage and advance these within and across diverse operational contexts, in consultation with sectors outside of science. The work of MMS, such as the OBPS, in supporting

interoperability and trust can contribute to developing strong, participatory communities of practice around the Ocean Decade Challenges and set an example for other communities of practice that emerge through the Ocean Decade. This is a foundation for transparency and communication of specific priorities across disciplines (one approach conceptually illustrated in **Figure 1**), furthering interoperable ocean research and applications, and for the understanding of regional and global processes that impact local resources, ecosystems, and communities.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

JP, PLB, CH, JK, and FM-K wrote the final manuscript. JH, AL-L, FP, RP, PS, JS, and RV contributed to early drafts of the manuscript. All authors contributed to the conceptualization and review of the manuscript.

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⁶ <https://marine.ucsc.edu>

⁷ <https://www.neonscience.org>

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Conflict of Interest: MB owns CoastalObsTechServices, and is employed by Integrated Systems Solutions.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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