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Food for Thought

Building on a human-centred, iterative, and agile co-design strategy to facilitate the availability of deep ocean data

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Current information on the status and trends of ocean change is needed to support effective and responsive management, particularly for the deep ocean. Creating consistent, collaborative and actionable mechanisms is a key component of the Deep Ocean Observing Strategy, a program of the United Nations Decade of Ocean Science for Sustainable Development. Here, we share an iterative, agile, and human-centred approach to co-designing datastreams for deep-sea indicators that serves stakeholders, including US National Marine Sanctuaries, presented as a four-phase project roadmap initially focused on the Monterey Bay National Marine Sanctuary, and then generalized to other areas such as the US West Coast, offshore wind development areas, and managed marine spaces globally. Ongoing efforts to provide key physical, biogeochemical, biological, and ecosystem variables for California's Marine Protected Areas are informing this co-design process. We share lessons learned so far and present co-design as a useful tool for (1) assessing the availability of information from deep ecosystems, (2) ensuring interoperability, and (3) providing essential information on the status and trends of indicators. Documenting and sharing this co-design strategy and scalable four-phase roadmap will further the aims of DOOS and other initiatives, including the Deep Ocean Stewardship Initiative and Challenger 150.

Keywords: Central and Northern California Ocean Observing System, co-design, data products, datastreams, Deep Ocean Observing Strategy, deep ocean, National Marine Sanctuary, spatial management.

Regular and reliable observations are required to assess the status of marine ecosystems, determine how they are changing, and evaluate management and policy actions to maintain ocean health, sustainability, and services, particularly in spatially managed areas. In the deep ocean, obtaining and sustaining observations is challenging and costly, but essential. The deep ocean represents ∼96% of the ocean by volume, is critical to climate regulation (Levitus *et al*., 2012), provides habitat for diverse biological communities (Ramirez-Llodra *et al*., 2010, Howell *et al*., 2020), and supports fishing, energy, and mineral industries (Ardon *et al*., 2019; Jones *et al*., 2021). Effective stewardship of deep-ocean resources requires the development of reliable collaborative pathways to ensure that observations address specific scientific and management objectives and are delivered in ways that allow for effective and responsive action (Levin *et al*., 2019).

The Deep Ocean Observing Strategy (DOOS), a program of the United Nations Decade of Ocean Science for Sustainable Development (UN Decade) and a project of the Global Ocean Observing System (GOOS; Tanhua *et al*., 2019), is meeting this need by facilitating connections between diverse groups of deep ocean stakeholders. DOOS is working to advance deep ocean observing capability and impact through a global network that engages observing, mapping, and modelling practitioners and deep ocean stakeholders with the objective of achieving UN Decade outcomes, including a predicted and accessible ocean (Levin *et al*., 2019; Smith *et al*., 2022). Co-design is one approach that can help structure effective interactions between stakeholders, allow for the identification and pairing of resources and needs, and promote the more informed and sustainable relationship with the ocean called for by the UN Decade.

The concept of co-design has roots in industry (Brown, 2009; Liedtka, 2011), and has since been applied broadly, including in conservation science (e.g. Iwamoto *et al*., 2019; Bowie *et al*., 2020). Co-design is any process that focuses on empathy and engagement with users as an integral part of the design process (Liedtka, 2011). It includes building relationships with users, engaging with them as early as possible, and incorporating feedback from rapid prototyping cycles that serve as opportunities for hypothesis testing. This process integrates well with agile software development, where developers work in interdisciplinary teams and prioritize frequent releases of operational software (Agile Manifesto, 2001).

Over the last 2 years, the Central and Northern California Ocean Observing System (CeNCOOS) and the Southern California Coastal Ocean Observing System (SCCOOS), both Regional Associations of the US Regional Alliance of GOOS [i.e. the Integrated Ocean Observing System, (IOOS); Rayner *et al*., 2019], partnered together to facilitate a co-design project. This project involved researchers collecting ecological monitoring data in California Marine Protected Areas (MPAs) (Figure 1), managers from California Department of Fish and Wildlife, and managers from the Ocean Protection Council (Ruhl *et al*., 2022), and had three objectives—data integration, dashboard development, and creation of custom syntheses—that collectively will inform the upcoming decadal review of the MPA network. More specifically, we supported this man-

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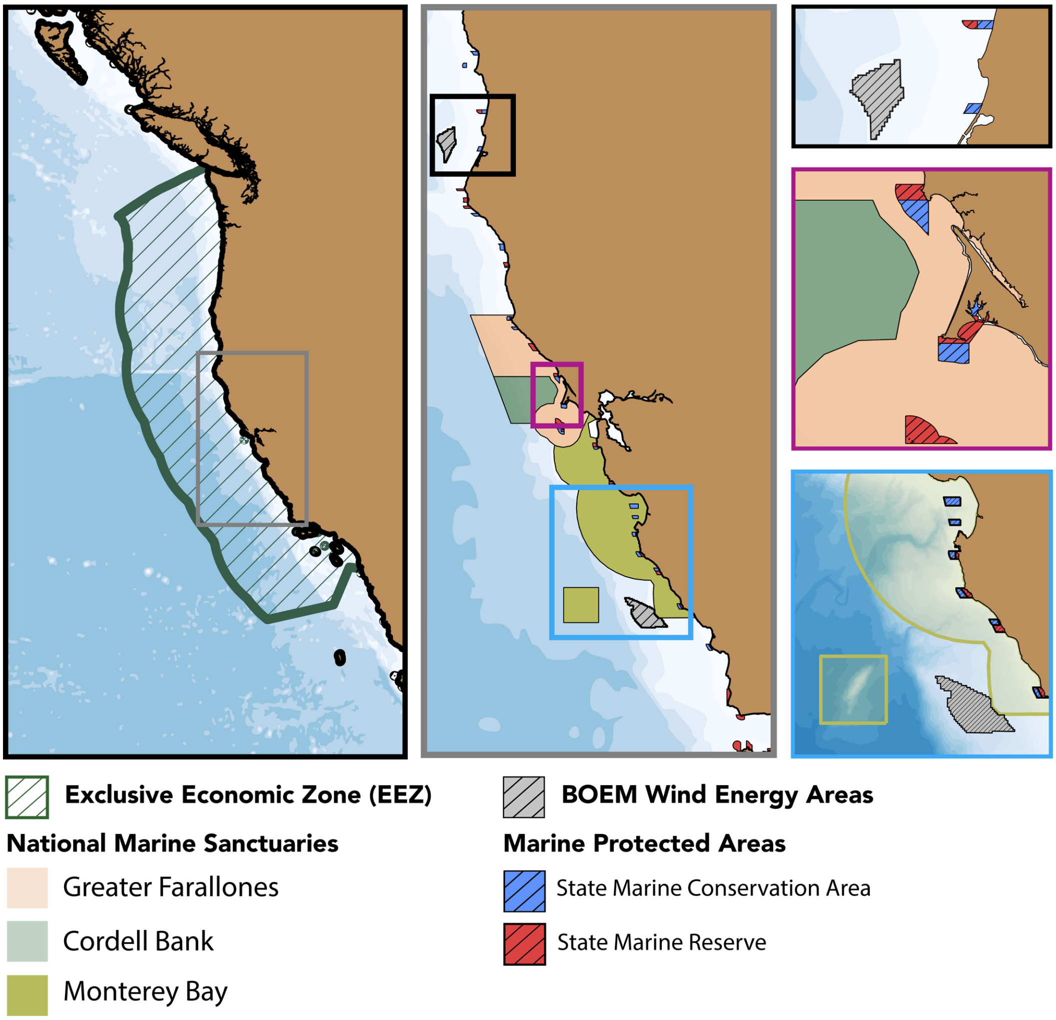

Figure 1. Maps indicating examples of spatial scope of prior, current, and upcoming work. The largest example illustrates the West Coast Exclusive Economic Zone (EEZ; left). The center panel focused on the central and northern California regions showing the Greater Farallones, Cordel Bank, and Monterey Bay National Marine Sanctuaries, and the offshore wind Call Areas of the Bureau of Ocean Energy Management (BOEM) in California, as well as the California MPAs in the region. Zooming in further, on the top right side are the Humboldt Call Area and nearby MPAs, on the middle right are portions of the Cordell Bank, Greater Farallones, and Monterey Bay National Marine Sanctuaries, and on the bottom right is the Morro Bay Call Area, portions of the Monterey Bay National Marine Sanctuary (MBNMS), including the David Seamount Management Zone to the southwest of the main Sanctuary area and nearby California MPAs.

agement objective by integrating ecological data with existing empirical, satellite-based, and model-based data products, enabling their display and download through an interactive online dashboard (https://mpa-dashboard.caloos.org), and creating custom data syntheses for each MPA and ecological monitoring team.

To ensure the usefulness of these data products, CeNCOOS and SCCOOS embraced aspects of both co-design and agile development. For example, we used information from informal interviews to develop prototypes and conducted cycles of demonstration and feedback with users to finalize products. The success of this strategy depended on our engagement with more than a dozen research groups (contributors to the Marine Protected Area Monitoring Action Plan, 2018) at both the Principal Investgator (PI) and early career levels and our ability to provide focused attention on cyberinfrastructure. These features created the capacity for focused conversations between responsive communicators. Our first objective, data integration, required clear communication around data sharing. Incentives were articulated early in the co-design process, including sharing requirements from project funding and a commitment that feedback would be incorporated wherever reasonable during ongoing co-design work to ensure that data were presented and used accurately. Based on this experience, we recommend a co-design approach if (1) there is sufficient capacity to facilitate the process (including ongoing, iterative engagement), (2) collaborative relationships can be built with participants who represent core stakeholders, (3) there is a clear management objective, and (4) the project emphasizes both feasibility and impact.

This year, DOOS is building on CeNCOOS's experience while furthering two of its objectives—identifying and filling data gaps and translating science to stakeholders—through a small-scale use case. MBNMS encompasses areas of deep ocean, including Monterey Canyon, Sur Ridge, and Davidson Seamount (Figure 1). It uses a reporting tool, called a Condition Report, to document the current status and trends in key

Table 1. List of semi-structured interview questions used with regional stakeholders.

What data exist? Enquire particularly into the date range of data collection and whether or not similar data are likely to be collected in the future.
What do I need to understand to use these data? Enquire particularly into data quality, limitations on conclusions based on how the data were collected, and any other challenges that may exist.
How can I access these data? Enquire particularly into whether the data are public or private, where they are kept (e.g. lab database, Google Drive, etc.), and what format they are in.
Who is the data creator(s)? Enquire particularly into whether the data creator(s) would be interested in sharing the data, and if so, in what way and/or under what conditions?
What are the blockers to data sharing? If the data creator(s) does not want to share their data, enquire into what incentives or reassurances they might need to change their mind.

ecosystem components, pressures on these elements, and related management responses (ONMS, 2009, 2015, 2018). The Condition Report is composed of standardized questions that articulate the management needs of Sanctuaries and set requirements for observing efforts (ONMS, 2018). These questions are

1. What are the states of influential human drivers and how are they changing?
2. What are the levels of human activities that may adversely influence water quality and how are they changing?
3. What are the levels of human activities that may adversely influence habitats and how are they changing?
4. What are the levels of human activities that may adversely influence living resource quality and how are they changing?
5. What are the levels of human activities that may adversely affect maritime heritage resources and how are they changing?
6. What is the eutrophic condition of sanctuary waters and how is it changing?
7. Do sanctuary waters pose risks to human health and how are they changing?
8. Have recent, accelerated changes in climate altered water conditions and how are they changing?
9. Are other stressors, individually or in combination, affecting water quality, and how are they changing?
10. What is the integrity of major habitat types and how are they changing?
11. What are contaminant concentrations in sanctuary habitats and how are they changing?
12. What is the status of keystone and foundation species and how is it changing?
13. What is the status of other focal species and how is it changing?
14. What is the status of non-indigenous species and how is it changing?
15. What is the status of biodiversity and how is it changing?
16. What is the condition of known maritime heritage resources and how is it changing?

Each sanctuary aims to address these questions by selecting location-specific indicators. Data for each indicator must be obtained from local observations; these observations are not yet well-developed for deep areas including in MBNMS. US Marine National Monuments with deep areas, such as the Mariana Trench and Papahānaumokuākea Marine National Monuments, have similar assessment needs.

DOOS is addressing this data gap by using the co-design process to develop datastream plans, i.e. standardized steps that connect a data source(s) to users who receive actionable information. We invited Monterey Bay sanctuary representatives to share their data needs, and then conducted semi-structured interviews with local researchers exploring the quality, limitations, accessibility, and sharing of existing data that could meet these requirements (Table 1). We identified existing datasets, including (1) deep ocean sound measurements that provide an assessment of vessel traffic (Condition Report Questions 2, 4), (Ryan *et al.*, 2021), (2) pH, temperature, and dissolved oxygen measurements from Remotely Operated Vehicle missions that provide information regarding seafloor temperature and the oxygen minimum zone (Condition Report Questions 6, 8), and (3) image and video observations of community composition that provide a reference for comparisons with future observations (Condition Report Questions 10, 12–15). Based on this initial effort, DOOS is evaluating the utility and design of these datastreams jointly with users, with the goal of providing sanctuary staff with information that addresses specific questions (i.e. reporting requirements) and enables a more informed assessment of the status and trends of deep ocean ecosystem components in the next Condition Report.

In this contribution, we provide a roadmap for identifying requirements, collating existing relevant information, prioritising and planning the collection of new observations, and developing new models, with the goal of providing improved time series developed from spatially relevant datasets that meet specific management needs (Figure 2). Phases 1–3 can be accomplished in about a year each; Phase 4 could take multiple years and include executing plans to secure new information identified in gap analysis and survey design, with timing depending in part on the scale and detail of new observing and modelling work. The roadmap is generalized enough that it can be tailored to other specific applications, such as providing information for the emerging GOOS Essential Ocean Variable for invertebrate distribution and abundance. For example, to address Condition Report Question 12 (*What is the status of keystone and foundation species and how is it changing?*), DOOS is aiming to provide targeted, updated datasets that can be used in habitat and ecological modelling over the next 2 years. This strategy can also be used to answer similar questions that are relevant to the UN Decade.

The small-scale co-design use case described here could benefit other nationally and internationally managed marine spaces. For example, marine ecosystem information will be needed for the planning and management of offshore wind-energy development on the continental slope off the US West Coast (Perry & Heyman, 2020) and of deep-ocean resource extraction in international waters (Ardron *et al.*, 2019). Using our roadmap as a template, we can more readily address these larger-scale use cases potentially expanding to the US West

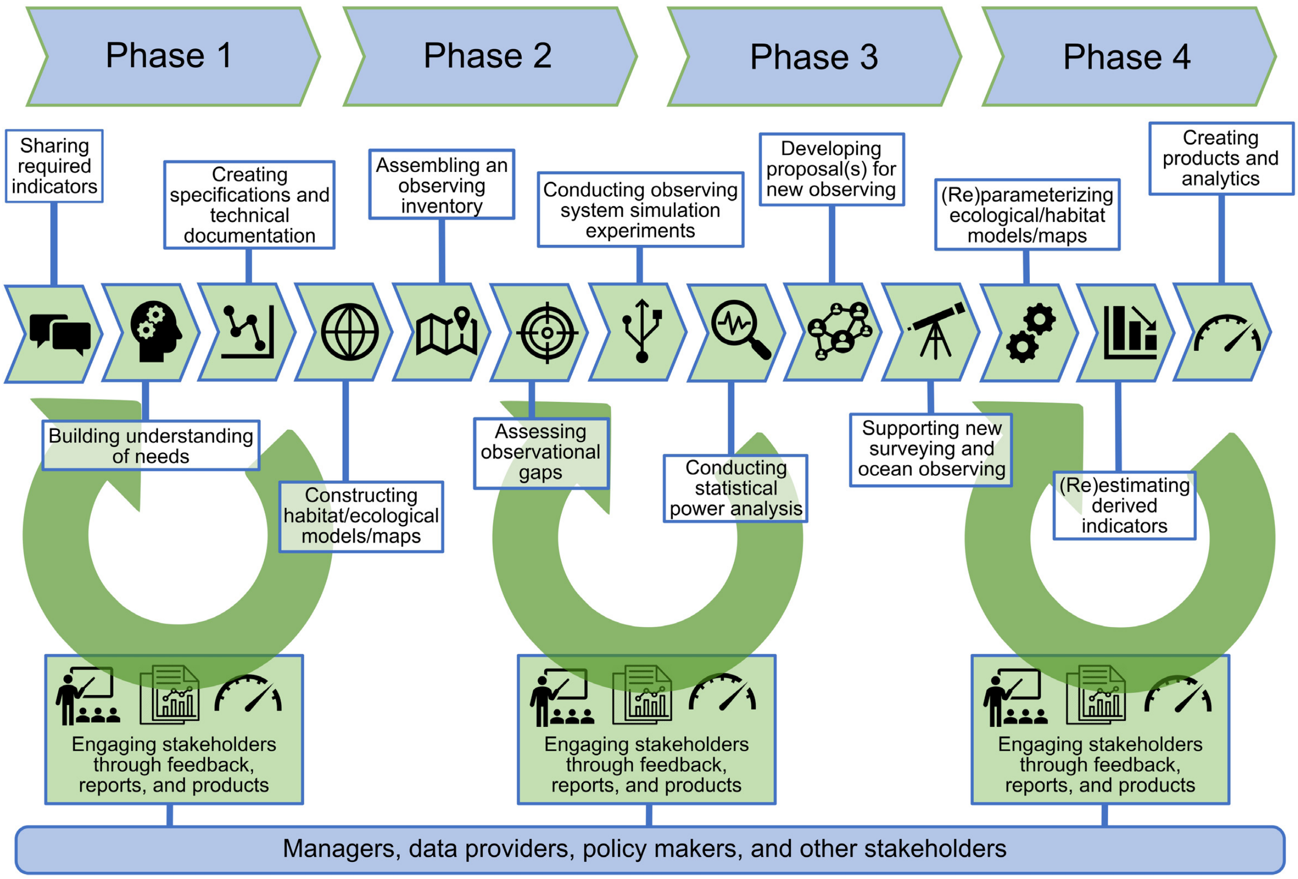

Figure 2. Suggested workflow and timeline for large-scale ocean observing co-design projects. Co-design for ocean observing must be driven by specific science and/or management needs, therefore our workflow starts (on the left-hand side of the diagram) with managers and experts sharing required indicators (e.g. indicators needed to address National Marine Sanctuary Condition Report questions) and stakeholders building understanding around these indicators and potential supporting or derived variables (e.g. estimates of size- and type-specific biomass). Next, each indicator is formally documented, e.g. through EOV specification and/or technical report documentation. The utility of these indicators in habitat and ecological models leads to consideration of additional variables and an observing data inventory and gap assessment. These subsequently underpin formal assessments, such as observing system simulation experiments and statistical power analyses, which, in turn, support proposals for future observing efforts. As new observations are gathered, habitat and ecological models are reparameterized, new estimates for derived indicators are obtained, and new relevant, actionable, and timely information is delivered. Note that cycles of stakeholder feedback and product development are required throughout this process, including where existing information can be used to inform some indicators, while plans for new observations are carried out to address others.

Coast EEZ. Documenting our work through explicit datastream plans and developing shareable toolkits will streamline user uptake while maintaining transparency and reproducibility (Ardron *et al.*, 2018; Benson *et al.*, 2021; Ruhl *et al.*, 2021). Through documentation, sharing, and on-going collaboration with DOOS and other initiatives (e.g. Deep Ocean Stewardship Initiative and Challenger 150), co-design is expected to emerge as a useful tool that helps facilitate science and management for the ocean we want.

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