Best Practices and Procedures for Operationalizing Marine Protected Area Network Monitoring

Synthesis of Global Insights and Recommendations for British Columbia's Northern Shelf Bioregion

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Rocky intertidal habitat monitoring, Farallon Islands, California © Sara Worden/CDFW

Executive Summary

Marine protected area networks (MPANs)—collections of marine protected areas designed to operate synergistically within a region—offer opportunities for habitat protection at large spatial scales while still allowing for diverse human activities. As communities and countries around the world forge ahead towards the establishment of MPANs to meet both local conservation objectives and global commitments to conservation targets, existing and new MPANs stand to benefit from the lessons learned by early adopters that are now undergoing retrospective reviews and evaluations. Drawing from five global MPAN case studies, review of reports and peer-reviewed literature, and expert interviews, this report presents global lessons and suggested best practices for operationalizing MPAN monitoring.

Part one of this report synthesizes emerging lessons for MPAN monitoring across a number of key monitoring topics. A companion Supplementary Report provides detailed case studies along with an in-depth literature review that supports the synthesized global best practices for MPAN monitoring.

Part two of this report places these global insights and best practices within the unique context of the Northern Shelf Bioregion (NSB) in British Columbia, Canada, where a network of MPAs is in the process of being implemented. The implementation of this network presents an important opportunity to *apply* the insights gained from existing best practices in MPAN monitoring from around the world to design an effective MPAN monitoring plan for the NSB. As such, this report offers a set of 31 recommendations for the development and implementation of a MPAN monitoring program for the NSB distributed across three core themes: 1) Early stages of implementation, 2) Data collection and management, 3) Analysis and Reporting, with additional detail on each recommendation in the body of this report.

Many of these recommendations are also relevant and applicable to other temperate regions that are in the process of designing or evaluating monitoring programs for a given MPAN.

Through careful consideration of the lessons and recommendations outlined in this report, partners working towards monitoring and management strategies in the Northern Shelf Bioregion and other emerging MPANs have the opportunity to set new precedents for integrated, collaborative, and rigorous social-ecological monitoring, evaluation, and management of these networks moving forward.

RECOMMENDATIONS FOR EARLY STAGES OF MPAN IMPLEMENTATION

- **R1.** Legislative or regulatory drivers for monitoring should be tied to a commitment of secure, long-term funding
- **R2.** Mandate monitoring and evaluation of the MPAN, not just of individual protected areas
- **R3.** Support First Nations in ways that ensure Indigenous Peoples and their knowledge systems play a central role in all aspects of MPAN monitoring design, collection, and analysis
- **R4.** Engage diverse partners and organizations in the process of MPAN monitoring design as early as possible to build mutual understanding, relationships, and support for ongoing collaboration
- **R5.** Clearly articulate key MPAN management objectives, levers, and triggers and identify monitoring questions and associated data needed to support decision-making processes for these levers
- **R6.** Link monitoring objectives to management objectives and their management levers
- **R7.** Adopt a linked social-ecological approach that can feed into adaptive management
- **R8.** Develop a plan for long-term human dimensions monitoring and research
- **R9.** Explore ways to monitor and assess the diverse outcomes and objectives of MPAN collaborative governance, with attention to the importance of reconciliation
- **R10.** Take stock of existing data and monitoring activities and build on these where appropriate, but develop new monitoring activities to fill gaps in for MPAN evaluation and management
- **R11.** Align baseline monitoring with the expectations and objectives of long-term monitoring
- **R12.** Coordinate and execute monitoring activities in ways that facilitate the flow of information necessary for knowledge integration and evidence-based decision-making
- **R13.** Establish trust, discuss data sharing needs, and negotiate data sharing agreements with monitoring partners as early as possible
- **R14.** Invest in strengthening local capacity for data collection, management, and analysis to enhance regional monitoring activities of the MPAN

RECOMMENDATIONS FOR DATA COLLECTION AND MANAGEMENT

- **R15.** Choose indicators through a transparent, collaborative, and repeatable selection process
- **R16.** Consider indicators that are relevant to multiple types of management questions and outcomes
- **R17.** Apply a monitoring prioritization framework across multiple indicators and sites to scale monitoring efforts to available resources
- **R18.** Develop sampling designs that will support robust with inferences about MPAN outcomes while anticipating the constraints of field logistics
- **R19.** Leverage emerging monitoring technologies to overcome regional capacity constraints and enable a wider range of indicators to be consistently monitored across the region
- **R20.** Select data collection tools, methods, and strategies in collaboration with local and Indigenous communities and other monitoring partners to align past and current cultural context, knowledge, and practice

Reef exploration, northeastern Vancouver Island, British Columbia © Jackie Hildering, TheMarineDetective.com

RECOMMENDATIONS FOR ANALYSES AND REPORTING

- **R21.** Decide on analytical workflows before data collection takes place and make the process transparent and repeatable
- **R22.** Choose analytical methods that are robust to the inevitable occurrences of unbalanced sampling or other irregularities in data collection
- **R23.** Consider the trade-offs between accessibility, complexity, and uncertainty when selecting analytical methods
- **R24.** Use monitoring data as inputs to state-of-the-art analytical methods to infer performance at a network scale, which would be difficult or impossible to measure directly
- **R25.** Plan for integrated analyses of social-ecological processes rather than evaluating the different domains of MPAN performance in isolation
- **R26.** Prioritize communications on monitoring progress and results, making use of multiple reporting outlets and modalities to reach different audiences
- **R27.** Set realistic expectations about anticipated outcomes and response times for key indicators and objectives following MPAN establishment when communicating with partners, decision-makers, and the public
- **R28.** Establish regular reporting intervals to ensure that managers, monitoring partners, and the broader community of marine users continue to value and support monitoring of the MPAN
- **R29.** Make monitoring data publicly accessible via online portals to increase transparency, accountability, and trust
- **R30.** Regularly evaluate the monitoring program and remain open to learning and adaptation

Arriving to monitor estuary, Vancover Island, British Columbia © Markus Thompson

Contents

Northern kelp crab, northeastern Vancouver Island, British Columbia

Twelve Apostles Marine National Park, Australia © Parks Victoria

Introduction

Marine protected area networks (MPANs) offer opportunities for marine protection at large spatial scales while still allowing for diverse human activities, including some types of fishing, within a region. MPANs are "*a collection of individual marine protected areas that operates cooperatively and synergistically, at various spatial scales, and with a range of protection levels, in order to fulfill ecological aims more effectively and comprehensively than individual sites could alone*."[1] As such, MPANs present a unique set of challenges for ecological, environmental, social, and governance monitoring that aim to link overarching MPAN goals and objectives to management levers and decisions (Figure 1). Establishing MPAN monitoring programs is challenging due to their large scale and the diversity across sites in protection measures, governance arrangements, representative habitats, remoteness, conservation objectives and priorities, cultural and community contexts, human activity pressures, and funding arrangements, among other factors. Moreover, there is added logistical complexity in coordinating data collection, management, and analysis across organizations and scales, ensuring adequate communication and reporting, and linking monitoring results to levers for management change.

Established and emerging MPANs across the globe are in a position to offer insights into what managers, partners, and institutions have learned and continue to learn from their associated MPAN monitoring programs. This is particularly true of some long-established networks that have recently reached important decadal or multi-decadal milestones associated with retrospective program evaluations. The purpose of this report is to gather and synthesize such lessons learned to enable their practical application in similar contexts. This effort sought to identify key considerations and best practices from a suite of place-based case studies rooted in applied monitoring experience and build upon them with additional insights drawn from the peer-reviewed and grey literature as well as discussions with key knowledge holders working in this space to support the design of MPAN monitoring frameworks moving forward.

In part one of this report, we present emergent and synthesized lessons for MPAN monitoring across a number of key monitoring topics including lessons for: monitoring design, baseline monitoring, indicator selection process, common and emerging MPAN monitoring indicators, data collection, management, and analysis for performance evaluation, communications and reporting, and pathways for informing adaptive management. It should be noted here that none of the case studies examined involved explicit engagement with Indigenous people and their knowledge throughout the establishment and implementation of these monitoring programs, although some indicate first steps being taken to rectify this situation in more recent years. While noting these shortcomings, we emphasize the central and leading role that Indigenous people and knowledge can play in MPAN monitoring.

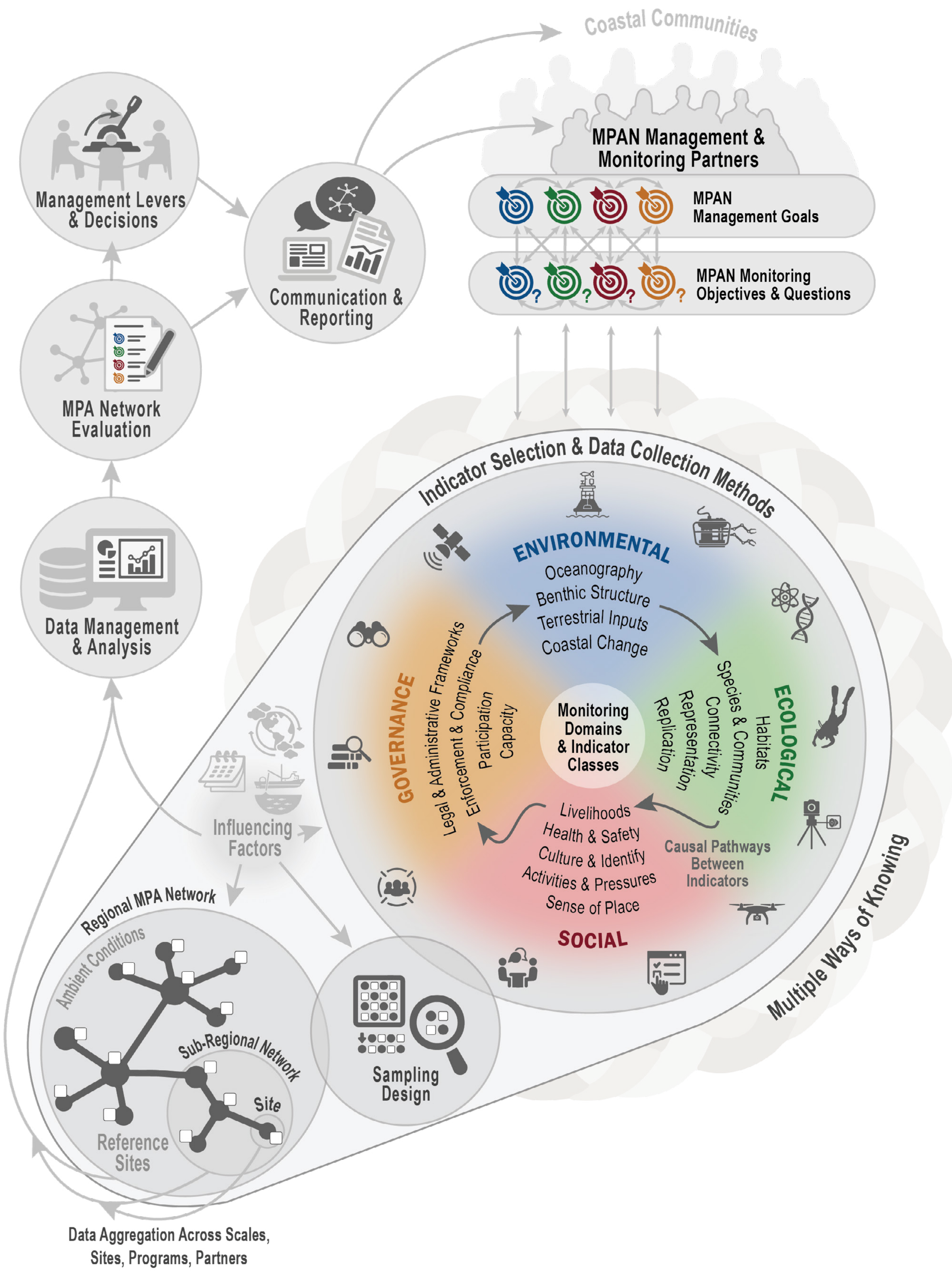


Figure 1: Overview of key elements of marine protected area network monitoring addressed in this synthesis.

Part two of this report takes these global insights and best practices and seeks to place them within the unique context of the Northern Shelf Bioregion (NSB) in British Columbia, Canada, where a network of MPAs is in the process of being implemented. In this region, 15 First Nations governments, the Canadian federal government, and the government of British Columbia have agreed to work together to establish a network of protected areas that will cover ~ 30% of the region (i.e., 30,500 km^2 of 102,000 km^2) and be collaboratively governed, managed, and monitored. Implementation of this network presents an important opportunity to apply, operationalize, and improve upon the insights gained from existing best practices in MPAN monitoring from around the world to design a cutting-edge, innovative MPAN monitoring plan in the NSB. Ongoing work on monitoring and management strategies will also provide the opportunity to set a new standard for the weaving of Indigenous and western science into the practice of MPAN monitoring and management. For example, the early stages of MPAN planning included the novel development of a robust method for the identification of Cultural Conservation Priorities that was rooted in Indigenous knowledge and informed the final network design.[2]

Drawing from the content synthesized in Part 1, our discussions with key knowledge holders, and the experiences and guidance from an Advisory Committee with a history of work in this region, this report offers a suite of monitoring recommendations for consideration within the specific context of the NSB, grouped into themes that encompass the early stages of monitoring, data collection and management, and analyses and reporting. Many recommendations are supplemented with practical examples and considerations of how these may be put into practice.

Juvenile tiger rockfish, Oregon © ODFW

Approach

Information in this report was synthesized from a combination of a global case studies, literature review, and expert consultations. Each of these approaches for gathering information and insights were multi-faceted:

- Case studies were based on MPANs in primarily temperate regions that have documented their experiences with planning and operationalizing monitoring. These case studies included MPANs in California (USA), Oregon (USA), the United Kingdom, Victoria (Australia), and Aotearoa New Zealand (Table 1). Information gathering for each case study involved a combination of literature reviews and engagement with practitioners and experts who have been directly involved in MPAN monitoring.

- A targeted review of both peer-reviewed and grey literature provided an overview of best practices for MPAN monitoring and complemented the case studies and expert consultations.

- A project Advisory Committee (acknowledged at the top of this report) helped to guide the direction of the case studies, literature review, and synthesis. This Advisory Committee was composed of experts with experience relating to marine or MPA monitoring within the NSB and included representatives of federal and provincial government agencies, First Nations organizations, marine science organizations, and academia.

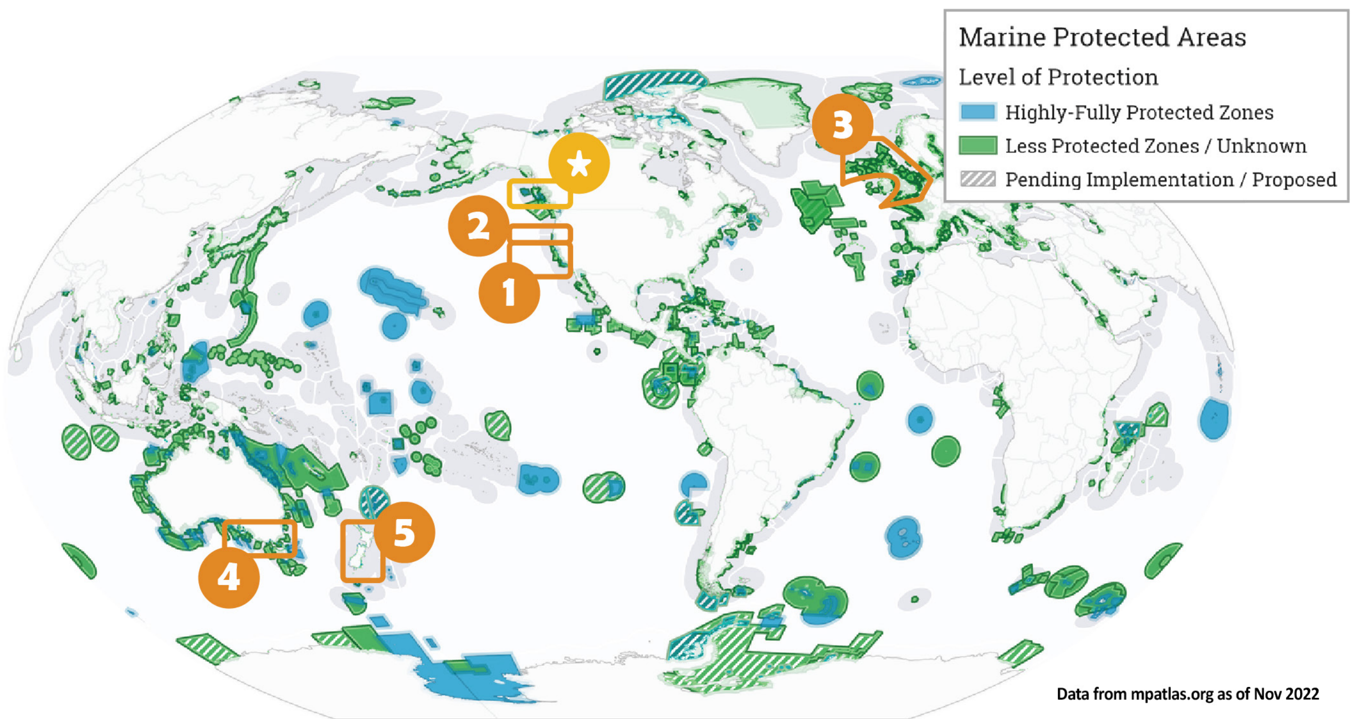
- A guided workshop bringing together international marine protected area monitoring experts and researchers working in the marine protected area space (Quadra Island, British Columbia, February 2023). This workshop was focused on linking social and ecological dimensions of MPA monitoring (see workshop report in the companion Supplementary Report).

- A series of consultations was also carried out with other experts who are involved in marine monitoring in coastal British Columbia through the following institutions: Coastal First Nations Great Bear Initiative Society, Province of BC, Fisheries and Oceans Canada, and Oceans Network Canada.

- Members of the consulting team also attended the 5th International Marine Protected Areas Congress (Vancouver, British Columbia, February 2023) and have incorporated relevant insights about MPA monitoring, research and practice that were gleaned from conference presentations representing the state of the art in MPA monitoring practice.

Along with this synthesis report, a companion **Supplementary Report** provides more in-depth coverage of monitoring topics touched upon in this document through more detailed literature review and full case studies. The Supplementary Report helps to provide additional evidence and further readings to support the lessons and recommendations synthesized here.

Table 1: Marine Protected Area Network Monitoring (MPAN) case studies in this report and their key insights.



MPAN Location	Case Study Key Insights
1 California, USA	• Strong focus on network-level ecological monitoring • Thorough evaluations and reports for monitoring outcomes • Longer term monitoring lessons (10 years)
2 Oregon, USA	• Human dimensions monitoring • Longer term monitoring lessons (10 years)
3 United Kingdom	• Indicators for large-scale monitoring • Coordination of monitoring across agencies and sectors
4 Victoria, Australia	• Monitoring insights for adaptive management • Longer term monitoring lessons (20 years)
5 Aotearoa New Zealand	• Development of a MPAN monitoring framework • Advanced planning of analyses and reporting
★ British Columbia, Canada	• New MPAN under development in the Northern Shelf Bioregion and the focus of the recommendations outlined in Part 2 of this report based in part on case study findings.

Kelp bass hunting school of salema, Laguna Beach State Marine Reserve, California © Steve Wertz/CDFW

Part 1: Global Lessons and Insights for MPAN Monitoring

1.1 Early Stages of MPAN Formation & Monitoring Design

MPAN monitoring and evaluation has been most effective in places where planning is initiated and supported by strong legislative drivers. Clear, legally mandated requirements for MPAN monitoring lead to effective and coordinated monitoring and evaluation programs. Establishment of MPAN goals within legislation helps to drive priorities and planning for monitoring. Best practices entail further connecting those broad MPAN goals and more specific objectives to monitoring goals and a monitoring plan so that monitoring and evaluation can directly inform future decision-making and adaptive management.

- The California Marine Life Protection Act (MLPA, 1999) set in motion the development and implementation of a MPAN across California's coastline. The MLPA included guidance on the development of the network as well as overarching MPAN goals and provisions for evaluating effectiveness of the MPAN towards meeting those goals, which requires monitoring.
- In Oregon, State legislation included a mandate for socio-economic monitoring, which led to the establishment of a strong human dimensions monitoring program.
- UK Marine strategy reporting is required every six years, aligned with reporting under several different legislative requirements.

Legislation mandating MPAN establishment and monitoring must be supported by commitments to long-term funding for implementation. Funding and capacity shortfalls have been cited as one of the major barriers hindering the overall performance of both management and monitoring of MPAs at a global scale.3 Securing consistent, reliable funding that can support dedicated infrastructure, programs, and personnel is essential to ensure sufficient capacity to consistently deliver on monitoring plans by collecting data at regular intervals at identified monitoring sites that align with required reporting timelines. Long-term funding also helps to reduce the risk of gaps in data collection that could jeopardize the ability to draw inferences about MPA effectiveness.

- In the California MPAN decadal review, partners noted it was critical they had adequate resources to regularly collect data at the same sites to build a consistent data set.
- In Australia, a retrospective review of Victoria's MPAN monitoring program recommended further diversifying funding models to ensure program resilience.

Conducting surveys about Oregon's marine reserves © ODFW

Strong coordination among partners and collaborators in the early design phases is important for implementation of MPAN monitoring. Research has repeatedly demonstrated that early inclusion of all MPAN partners—and other key actors—is essential for sustained, long-term success.[4,5] This will be particularly relevant for MPANs which are largely remote and sparsely populated and will rely strongly on partnerships with local and Indigenous communities and organizations to carry out monitoring activities. Development of a monitoring plan and framework will involve discussion around many considerations, such as identification of key species/habitats and selection of relevant indicators, data ownership and sovereignty, and responsibilities for each partner. Further considerations for monitoring partnerships are outlined in the section on Data Collection.

- Monitoring has been enabled in each of the case studies through establishing coordinated partnerships with different monitoring programs and subject-matter experts. In Oregon and California, monitoring has been largely coordinated by government agencies, but led by university researchers with expertise in a particular habitat, species, or topic. In contrast, monitoring in the UK has been supported strongly by the Marine Environmental Data and Information Network (MEDIN) which enabled the use of existing data and data collection programs wherever possible to establish baselines and realize efficiencies.

MPAN monitoring and evaluation frameworks need to address network-level questions while simultaneously allowing for site-level monitoring priorities. In addition to questions about representativeness, connectivity, scale, and other key network design features, individual sites within a MPAN—which may encompass different habitats and species, levels of protection, and jurisdictional authorities—will have local-level conservation or human well-being objectives that may also need to be prioritized for monitoring. For instance, a site that was protected due to the presence of a particular species that has been heavily fished or that has a restricted geographical range may require types of monitoring that are not required at other sites.

- California's decadal review refined and added to a series of evaluation questions that were originally laid out in the MPA Monitoring Action Plan (2018).[6] Refinement of these evaluation questions helped to better emphasize monitoring necessary for addressing network-level performance and evaluation (Appendix 1 and 2 in Scientific Guidance for Evaluating California's Marine Protected Area Network).[7]

MPAN monitoring programs require dedicated and specialized program staff to support holistic monitoring. Coordinating monitoring, analysis, and reporting activities over multiple sites across a large MPAN is difficult to achieve amid competing responsibilities and should be carried out by dedicated personnel. Human dimensions monitoring in particular, encompassing social, cultural, and economic activities and impacts, is frequently neglected within monitoring programs and is also deserving of dedicated staff with different skillsets than needed for managing ecological aspects of monitoring programs alone. Human dimensions monitoring has also been widely acknowledged as critical for understanding perceptions about the value of MPAs and MPANs, and to inform decisions that address human behaviors that can influence ecological outcomes. From a governance perspective, MPAs are essentially sets of rules that aim to influence human activities. Thus, understanding how communities and stakeholders have responded to MPANs is also important for fully appreciating where and how MPANs have affected human pressures on marine ecosystems. Part of supporting human dimensions monitoring means having qualified full time staff leading programs.

- The Oregon experience has demonstrated the value of having experienced human dimensions scientists for establishing and conducting a robust human dimensions research program. This level of expertise was necessary to provide applicable and useful resources for managers and decision makers. Oregon has also shown how core funding is essential to implementing and maintaining long-term monitoring partnerships and attracting additional resources by demonstrating state commitment and enabling leveraging of additional grants and resources.

Effective coordination across many different monitoring partners and programs is essential for ensuring that monitoring programs enable efficient and effective knowledge integration that is relevant for evidence-based decision-making. Coordination of monitoring activities involves a collaborative crosswalk across monitoring designs and methods for each indicator or parameter of interest to understand overlaps in focal indicator, technology, time, and space considerations. The framework for knowledge integration in Figure 2 shows how knowledge production at multiple levels flows into higher levels of knowledge synthesis and decision-making. This pathway of information flow can be populated for each individual monitoring question and related management decision, and these pathways can then be grouped into adaptive problem maps to understand how multiple streams of monitoring data can contribute to one or more management decisions. Importantly, local and Indigenous knowledge should be intrinsically embedded within each step of this framework rather than treated as its own siloed element.

Monitoring coordinators are advised to map the path of information flow required from *each* management decision and related monitoring question of interest to determine what types of analyses must be carried out, what types of data are needed and when certain types of data can serve as timely inputs to those analyses, and which organizations, programs, and individuals and responsible for collecting, collating, and integrating those data both horizontally and vertically to support analysis. The intent of the knowledge integration framework is to find opportunities to align monitoring protocols and designs and maximize sampling efficiency by co-locating monitoring for different indicators and parameters in time and space to reduce overall effort and collect synchronized data that facilitates the contextual analysis of relationships between indicators.[8,9]

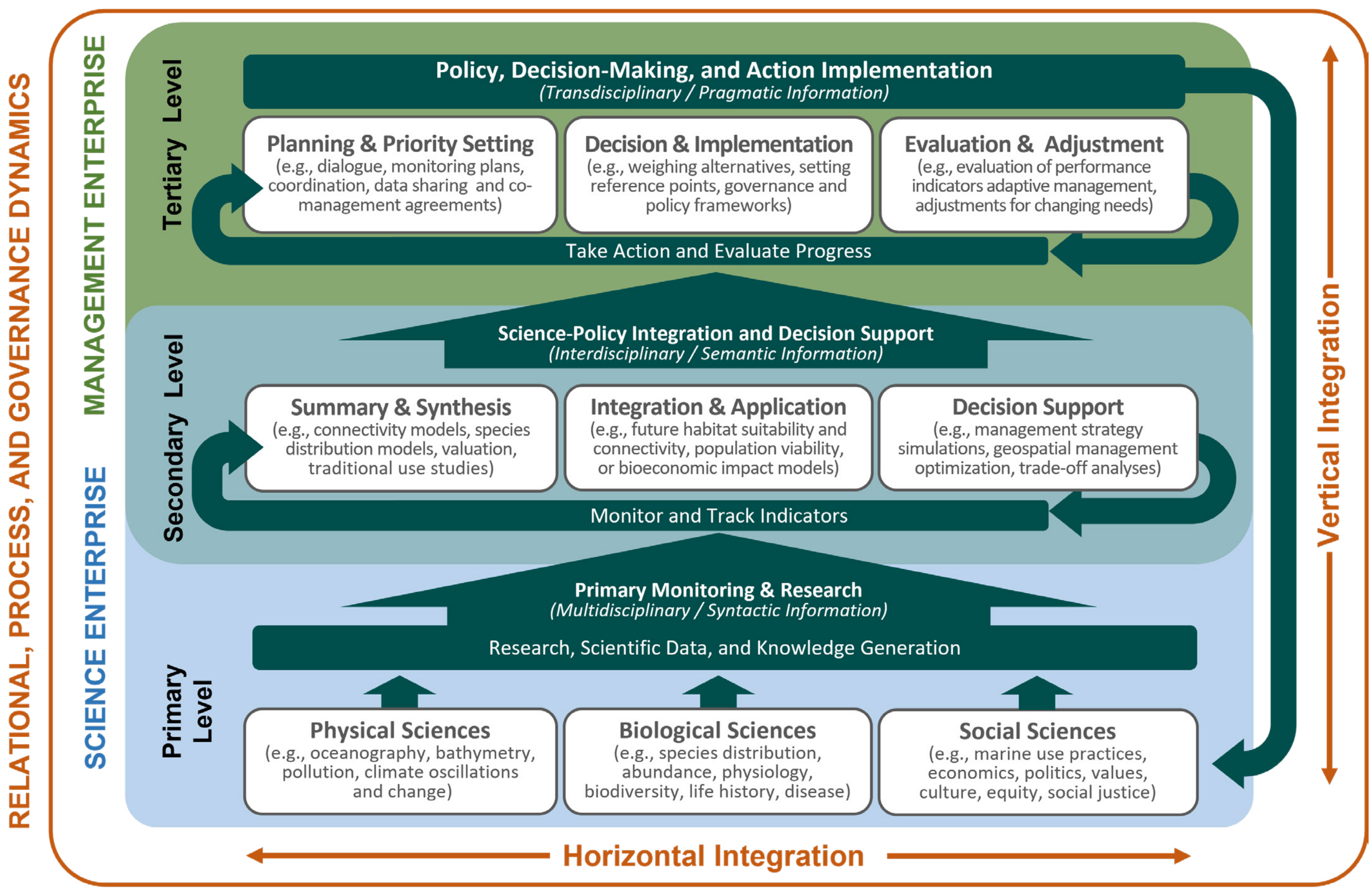


Figure 2: A framework for knowledge integration across the science to management continuum[10] with examples from the context of MPAN monitoring and management. Activities within each level of knowledge production contribute to higher levels of knowledge synthesis and decision-making, and the quality of both this information and the resulting management decisions and outcomes are improved by strong horizontal and vertical integration within and across levels and types of knowledge production. This framework operates within and is inextricable from the social fabric of people, relationships, information sharing processes, and governance dynamics unique to each MPAN context. Importantly, local and Indigenous knowledge should be intrinsically embedded within each step of this framework rather than treated as its own siloed element.

Ecklonia Overunder Reef Life Survey, Cape Howe, Australia © Parks Victoria

1.2 Baseline Monitoring

Network-wide baseline data collection prior to implementation of an MPAN is ideal to support long-term assessment, although this has not been a widespread practice to date due to practical constraints.[11,12,13,14] In the case studies examined, most MPANs did not collect intentional systematic network-wide baseline data prior to implementation of the entire network. Ideally, all MPA and reference sites would have completed baseline or 'before' monitoring of key indicators at multiple timepoints prior to MPA establishment, but in practice baseline monitoring typically takes place within the first few years following implementation of zoning and management plans. This generally precludes the use of before-after sampling designs, which reduces the ability to draw inferences. In some cases, baseline information is already available for some indicators collected through existing monitoring programs. However, gaps are likely to remain, particularly given that those programs were not designed with MPA effectiveness evaluation in mind. Most MPANs do have forms of data available (e.g., data from fisheries or existing MPAs or monitoring sites) that may complement baseline data, but these data may not meet the same needs as purposeful, network-specific data collection on indicators of interest.

- Part of the reason for delayed development of a MPAN monitoring plan in California was the sequential implementation of the network across its four regions. As the network was implemented in each region along the coast, baseline data were sequentially collected over the period from 2007-2018.

- In Oregon, research studies were conducted prior to and then subsequent to marine reserve designations. Baseline data collection was initiated from 2009 to 2016. After 2017, the research focus was adapted to emphasize comparative longitudinal studies, with less emphasis on baseline characterization of ocean users and coastal communities.

Coordinated collection of existing and new baseline data can serve a wide array of purposes that support further MPAN planning.[15,16,17] Additional uses of baseline monitoring often include: characterizing key features, establishment of monitoring priorities, selecting long-term monitoring and reference sites, understanding relationships between variables, and providing context for setting expectations about MPA outcomes (e.g., how starting conditions may influence the magnitude and trajectory of recovery). While some existing data are likely to be available towards these ends, there will inevitably be gaps in available information that require additional baseline data collection.

- The California MPA Monitoring Action Plan categorized sites into prioritized tiers that help to prioritize where to monitor when funding is limited (i.e., Tier 1 sites are 'required'). Based on analysis of baseline monitoring along with other criteria, the tiers were designed to reflect how well sites align with the quantitative criteria for each tier.

- Oregon collected baseline information to develop social, cultural, and economic characterizations of communities of place (e.g. towns, ports) and the fishing occupational community (i.e. commercial and charter fishing) located near marine reserve sites. This enabled subsequent community studies and use of relevant secondary data to inform trends in social welfare and economic conditions of coastal communities.

- In the UK, considerable efforts were made to take stock of existing monitoring programs and data sources that could be used to establish long-term baselines, and that were particularly relevant for features such as seabird abundance and breeding success

Aligning indicators and methods with existing long-term monitoring efforts can create future efficiencies. A consideration for developing and implementing a new MPAN is to reflect on how data collected at different sites, different years, and sometimes for different purposes may be aligned for contribution to long-term monitoring. Any data that can contribute to a longer time series can be very helpful when evaluating MPAN trends and impacts 10 or more years into the future.

- Linking baseline data to long-term monitoring was not done on a broad scale in California. However, a lesson emerging from a decadal review of this case was that collecting baseline data in ways that could also contribute to long-term monitoring datasets (e.g., using methods and sites that would also be included in long-term monitoring) would have helped with integration and comparisons later in the adaptive management process.

- Data for many of the indicators in the UK were drawn from existing long-term monitoring programs for species such as seabirds and seals. Data collection programs were also strongly aligned with other monitoring requirements, such as the OSPAR convention for the North-East Atlantic and Water Framework Directive, which allows the UK to realize synergies and efficiencies to ensure the sustainability of monitoring programs.

1.3 Categories of MPAN Monitoring

MPAN monitoring frameworks can and should be designed to serve several critically important functions. These 'functions' can be grouped into four categories for MPAN monitoring (below) that emerge from case studies and the literature, which collectively provide important insights about the status and trends of marine ecosystems and human pressures, the impacts of the policies and programs, and knowledge about the marine environment:[18,19,20,21]

1. **Ambient condition monitoring collects and analyzes data to assess the broader-scale environmental or human dimension trends.** This type of monitoring is an important measure of MPA effectiveness in its own right and is also necessary to incorporate covariates and confounding factors in data analyses to help disentangle the causal drivers of MPA outcomes and ensure that observed effects can be attributed to protections rather than broader environmental or socio-economic change. **Ambient condition monitoring can include key marine environment and ecosystem parameters** (e.g. regional patterns in climate variables, ocean temperature, dissolved oxygen levels, pollution levels, habitat condition, the abundance and diversity of species), **human dimensions** indicators (e.g., income, catch rates, and well-being) and **governance** attributes (e.g., stakeholder participation, funding, and enforcement). Ambient condition monitoring can occur at several different scales, both outside and inside MPAs, but is often most useful when data are collected at smaller scales and enables aggregation for assessment at larger scales.

2. **Human pressure monitoring collects and analyzes data concerning human activities that impact the marine environment.** These can include social and governance indicators such as rule compliance, patterns related to human use of the marine ecosystem and ecological measures of parameters such as anthropogenic emissions or environmental concentrations of contaminants. Given that the primary purpose of an MPAN is to reduce human pressures to allow for ecosystem recovery, monitoring human activities and pressures themselves is fundamental for understanding whether the intended protections are being realized, and to provide leading indicators of the effectiveness of an MPAN where ecological recovery may take years or decades to recover. Thus, human pressure monitoring relates closely to compliance and enforcement. Activity monitoring through direct observation, electronic tracking, and other methods can help to inform when and where to allocate effort for patrols to further investigate rates of compliance and intervene with enforcement activities when needed.

3. **MPAN performance monitoring is explicitly designed to move beyond monitoring the status and trends of parameters to isolate the causal effects, effectiveness, or performance of MPAs**. This type of monitoring can be carried out for individual MPAs or collectively across networks, with respect to key pressures and management goals and objectives. MPAN performance monitoring typically benefits from a strong research design that includes sites both inside and outside (e.g., nearby 'control' or 'reference' sites) of MPAs or the broader MPAN, with measures before and after the introduction of MPAN restrictions. Typically this type of monitoring is focused on changes in indicators for key valued social-ecological features, but should also include monitoring of broader environmental conditions and other factors (e.g., history of prior fishing pressure, size of MPAs, duration of protection, compliance and enforcement activities, etc.) that are known to influence the trajectory and timelines of MPA effects.

4. **Ecological reference monitoring uses MPA sites themselves as reference points for better understanding the effects of global and regional-scale pressures** (e.g., climate change, diffuse pollution, and regional-scale fisheries on marine ecosystems). This is particularly true for effectively managed no-take and especially no-entry MPAs, where the effects of broader-scale pressures are not confounded by the effects of local human activities that are excluded from these sites.

1.4 MPAN Monitoring Indicators

Evaluating the performance of MPANs requires monitoring a diverse range of indicators relating to social-ecological values of the network as well as other factors that may influence whether they meet their objectives and how long this process might take. MPA monitoring indicators are numerous and diverse, but can generally be related to four broad domains—**environmental, ecological, social, and governance**—which are the focus of this section (Table 2). Influencing factors that may affect the response of indicators in these domains and should also be taken into account, including the historic and pre-existing levels of fishing (e.g., compliance or non-compliance with regulations) and other human pressures in and near MPAs, species biology (e.g., life span, speed of reproduction, etc.), and climate variability (e.g., El Niño events, variation in climate change vulnerability across the region). Other design-based factors that can also affect outcomes include the level of protection assigned to MPAs and zones within MPAs, the specific types of monitoring parameters chosen, and the frequency at which parameters are measured and reported on. Depending on the interplay between these external and design-based factors, ecological recovery can require ten years or more to be fully observable.

A. ENVIRONMENTAL INDICATORS encompass physical ocean characteristics, including ocean circulation, substrate, coastal features, bathymetry, acoustics, temperature, elements of water quality (e.g., salinity, pH, dissolved oxygen, nutrients, etc.), land-sea connections influencing physical and chemical variables, and others.[22]

While environmental variables generally are not included in lists of 'leading indicators' of MPAN performance, they are important to include in an indicator portfolio.[23,24] These indicators can provide direct insights into MPA effectiveness in their own right and are also important influencing factors to control for in monitoring design and data analyses to help disentangle causal relationships driving MPA performance and ensure that outcomes can be appropriately attributed to MPA implementation rather than background environmental variability and change, particularly in the context of global climate change.

- In the UK, Kittiwake breeding success is known to be strongly influenced by local mean sea-surface temperature in February and March of the previous year. Collecting data on these parameters therefore allows managers to isolate the effects of marine policies on Kittiwake breeding success.
- In the Northeast Pacific ocean, local seawater chemistry is known to be influenced by kelp beds and broader changes in ocean chemistry.[25] Collecting data on ocean chemistry could similarly help managers to understand the recovery of kelp ecosystems following protection.

Kelp forest, Scotland © Joint Nature Conservation Committee/Marine Scotland Science

B. ECOLOGICAL INDICATORS include a wide range of species, community, and network-scale indicators and are by far the most commonly measured indicators of MPAN effectiveness across all domains.[26,27,28] Although many ecological indicators have been used in MPA monitoring to date, recent studies have shown that some more infrequently used indicators are much more reliable for detecting a 'MPA effect', or differences in ecological communities inside and outside of MPAs, than more commonly used indicators.[29,30]

At the species scale, species-specific total biomass, density, or mean size are the most commonly used indicators of MPA effectiveness for species recovery. However, studies have shown that species-specific population size distribution and population density by stage (i.e., age, size or, maturity stage) perform much better as indicators of MPA effectiveness.[31] Mean body length can also be indicative of MPA effectiveness for species strongly targeted by fishing prior to MPA establishment.[32] Species-level indicators that are more challenging or resource-intensive to measure are typically limited to focal species, with focal species abundance and population structure representing the primary indicators used for assessing MPA management effectiveness itself.[33] Importantly, these indicators are less likely to change after MPA establishment for areas with little or no prior history of fishing.

At the community scale, species richness and diversity are the most common or 'leading' indicators in use across MPANs, and are typically applied to assessing ecological representation and replication rather than as measures of MPA effectiveness. However, studies have shown that total biomass and total abundance are more reliable predictors of MPA effects on ecological communities.[34,35] Where biodiversity is of particular interest, studies have shown that evenness, functional diversity, and phylogenetic diversity are more reliable community-scale indicators of MPA effects on diversity itself than species richness and diversity. Where resources allow, pairing measures of total abundance and total biomass with measures of evenness and diversity are more likely to capture multiple dimensions of MPA effectiveness at broader community and ecosystem scales.[36,37]

At the network scale, key effectiveness indicators include representation, replication, and connectivity. All of these are strongly linked to the size, spacing, arrangement, and protection levels of MPAs within the network that are set in the planning stages. However, ongoing monitoring of these indicators is important because each may also change from their initial condition upon MPAN establishment depending on the degree of MPAN effectiveness and cascading effects on species and community-scale indicators.[38,39,40] For example, these indicators may change for the better if effective management results in increasing population growth and connectivity that leads to the establishment of species or habitats at new sites (e.g., population growth of a species at one site associated with appearance of that species at an nearby MPA site where it was not previously present), or for the worse if ineffective management leads to the disappearance of species or habitats from specific sites (e.g., loss of eelgrass, kelp habitat, or glass sponge habitat due to pollution, illegal harvest, or physical damage from illegal bottom trawling or anchoring). In these ways, network-scale indicators can also be thought of as another way to analyze emergent effects of an MPAN on species, habitats, and communities.

Connectivity is extremely challenging to measure directly, and is most often assessed through network connectivity models that use information on the size and location of sites, ocean currents, and recent monitoring data on recruitment of focal species across sites as key inputs. For example, long-term monitoring data on juvenile recruitment have been used as inputs to habitat and population connectivity models in California's MPAN to assess how connectivity may be changing over time in response to protection and other factors like climate change.[41,42] These models can be validated and refined using additional empirical data on fish population dynamics, such as genetic analyses of gene flow and population connectivity.[43] Similarly, monitoring data on environmental conditions, habitats, and adult species distributions used to develop species distribution models in BC[44] could be repeated in the future to monitor changing habitat suitability across MPANs at multiple spatial and temporal scales for evaluating changes in species representation across an MPAN.

C. SOCIAL INDICATORS related to MPANs distinguish between core categories of indicators, including livelihoods, health and safety, culture and identity, and social relationships.[45,46,47,48,49,50,51] There are numerous ways to categorize social indicators, including categories of tourism and recreation, justice and equity, and wellbeing. Much like the environmental and ecological indicators, the relevance of specific indicators is influenced by site and network contexts such as the relative importance of different livelihoods, and the interests, values and needs of adjacent communities. These factors should be carefully accounted for in the design of monitoring and analytical frameworks.

Most monitoring programs that include social indicators emphasize livelihoods, particularly fishing livelihoods, but also recommend that tourism and other livelihoods be considered. Many experts and monitoring programs recommended moving beyond just livelihoods to monitor the status and trends of other social indicators including **vulnerability and adaptive capacity** of groups to climate change and extreme events**, access to nutritious and affordable food,** maintenance of **cultural practices and traditions,** and degree of social **conflicts and compatibilities among marine users.**

- In California, semi-structured focus groups were used to elicit impacts of the MPAN on commercial fisheries across a range of different dimensions, including job satisfaction and social relationships, providing measures of these concepts and insights about the factors that may be influencing them.[52]

- Semi-structured interviews were also used across six communities in Oregon to better understand their adaptive capacity to climate change and other stressors, including MPA rules.

Evaluating stakeholder perceptions can offer an important lens for evaluating the ways that MPAs impact local communities. Monitoring the ways that people feel that themselves and others inside and outside of their communities are impacted socially and economically by MPAs is important for understanding the extent of support for MPAs. Perceptions research and monitoring can feed into broader social and governance monitoring. Furthermore, people's perceptions of positive or negative outcomes for marine ecosystems can influence their support for MPAs.

- Oregon is the best example from the case studies where significant effort was put into monitoring social indicators, including attitudes and perceptions of implementation and management (see Oregon case study in Supplementary Report).

It is beneficial to include indicators of social factors that do not directly measure impacts but, rather, indirectly drive those impacts. These could include changes in fishing inputs and costs as well as markets and prices that may exacerbate economic impacts. As another example, tourism market information about environmental preferences and motivations can inform the development of initiatives, promotional materials, and educational activities.

- In Oregon, visitor intercept surveys were used to develop a better understanding of (a) the level of awareness of Oregon marine reserves and (b) motivations for visiting these locations which could be used to inform the design of promotional activities.
- Aotearoa New Zealand's Marine Monitoring and Reporting Framework (2022)[53] groups indicators within 10 themes. Theme 7 is on understanding human uses of and relationships with marine reserves (i.e., human impacts).

Progress in identifying social indicators, developing monitoring methods, and undertaking monitoring of the social dimensions of MPAs in general, and MPANs in particular, has generally been slower than for environmental and ecological dimensions and should involve participatory processes to engage affected groups.

D. GOVERNANCE INDICATORS of MPANs encompass a wide range of dimensions, including legal and administrative frameworks, property rights, stakeholder participation, capacity, integration, compliance and enforcement, and education and knowledge, most of which serve to enable effective and lasting conservation.[54,55,56] These indicators may be based on desk-based assessment of documents (e.g., number of plans, adequacy of budgets, etc.), on measures of governance activities (e.g., numbers of public meetings, patrols, educational events, etc.), or through primary data collection (e.g., surveys, interviews, or focus groups) which can ensure that policies and activities are having their intended effects.

- Based on the Marine Monitoring and Reporting Framework (2022), in 2023 Aotearoa New Zealand will be piloting the use of a custom made app that will be used by marine reserve rangers to track their interactions with people during patrols (e.g., compliance rates).
- It is often best to combine activity-based indicators that detail the number and diversity of participants, along with indicators derived from surveys, interviews and/or focus groups to develop a better understanding of participant experiences, perceptions, and outcomes.

Similar to social indicators, case studies show that progress to identify relevant governance indicators tends to be slower than ecological and environmental indicators. Across the case studies, some of the commonly measured governance indicators relate to MPA compliance and enforcement. However, it is notable that indicators related to inclusion and participation, capacity, and adequacy of legal and administrative framework are essential for understanding the extent that governance systems are set up to support other aspects of monitoring.

CROSS-CUTTING INDICATORS FOR MPAN MONITORING

E. CLIMATE CHANGE INDICATORS Notably, many of the same indicators used for monitoring the general effectiveness of MPAs in other indicator domains are also useful for understanding broader climate change effects with appropriate sampling and analytical approaches specific to this context. For example, climate-relevant indicators may focus on capturing changes in species distributions and assemblages in response to predicted range shifts and changes in marine use and behaviour that may be driven by changing marine weather conditions. These indicators may be monitored within a broader context that considers current climate change projections identifying areas of relative risk or refuge as well as climate-driven ecological thresholds that may provide early warnings for phase shifts that warrant a shift in management management strategies.[57,58]

F. Integrative Social-Ecological Indicators Suites of indicators may include indicators from different domains that reflect the status of individual components of a social-ecological system, but do not always explicitly consider how to monitor changes in the relationships of linked indicators in ways that more accurately reflect the interconnectedness within social-ecological systems. One approach to better represent this interconnectedness in suites of indicators is to include **causal indicator chains**, where environmental and ecological indicators are linked to indicators for the specific ecosystem services that they support, which are in turn linked to the social value generated by those ecosystem services[59] (Figure 3). Indicators relevant to the ecosystem services along these causal chains are known as **benefit-relevant indicators (BRIs).** BRIs can be useful for integration of information on cascading responses to a management action, in this case MPAs, across multiple domains of the social-ecological system by moving beyond measurement of changes in state to providing insights into changes in processes as well. BRIs can act as a proxy indicator for changes in social value indicators themselves, which can be more challenging to measure in practice.[60]

This concept can be expanded to encompass not only the many ecosystem services MPAs can provide to people[61], but also the many 'services to ecosystems' that people can provide in return.[62] Including this feedback loop acknowledges the deep history of stewardship by Indigenous Peoples over their ancestral lands and waters that has played, and continues to play, its own integral role in maintaining ecosystem function as part of an ongoing reciprocal relationship.[63] Benefit relevant indicators are strongly aligned with the principles underpinning biocultural indicators, which are rooted in local values and place-based relationships between nature and people and require consideration of interconnectedness, linkages to human well-being, and cultural salience.[64]

The use of causal indicator chains can help to pinpoint the weak link in this chain that may be limiting the anticipated benefits of protection in an MPA to allow for a more targeted management response. For example, if monitoring demonstrates that a human pressure is still occurring despite regulations, further education, compliance, and enforcement may be needed. If the pressure is no longer occurring, but expected benefits to ecosystem function don't appear, influencing environmental factors may be an issue, and if the ecosystem recovers but communities are not experiencing the expected benefits, social or economic constraints such as limited access may be responsible.

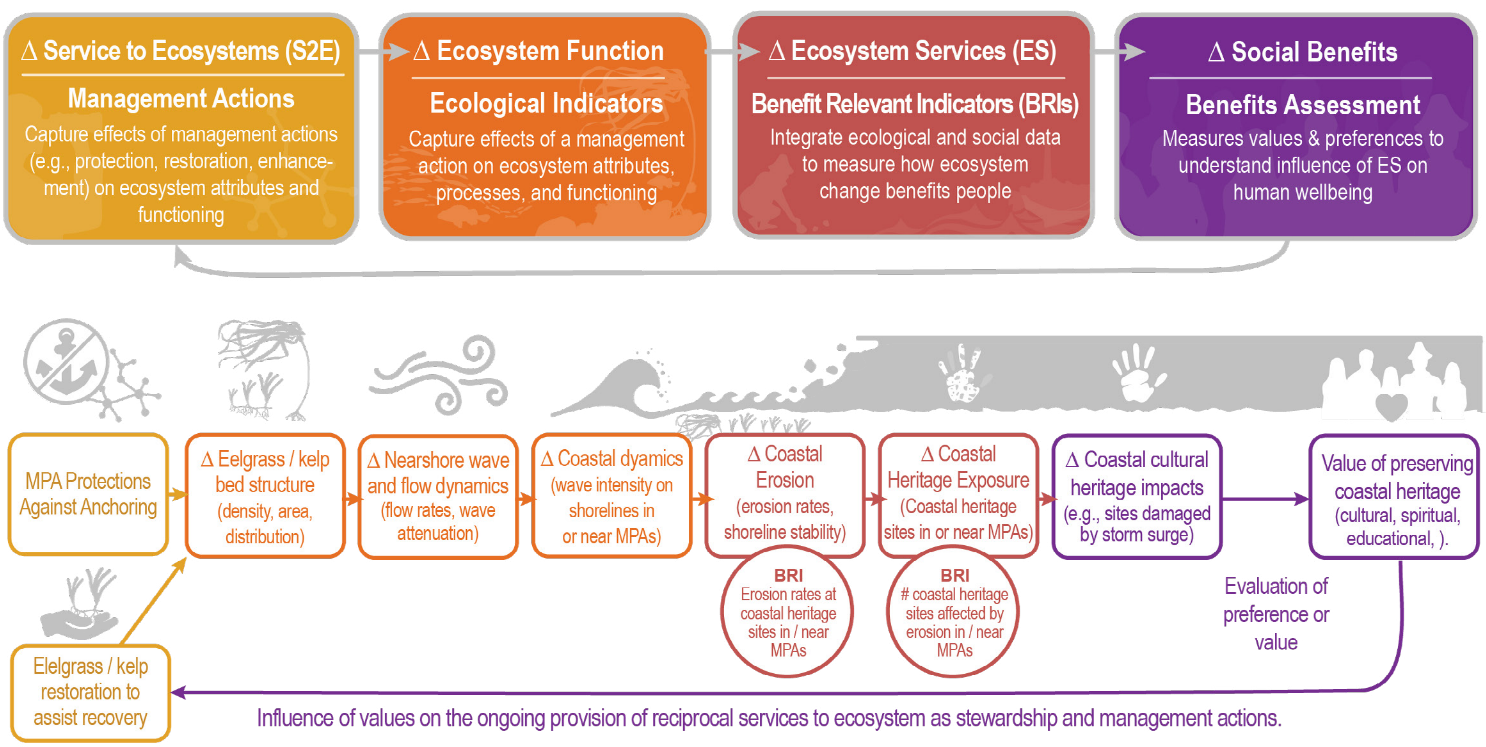


Figure 3: Example of a simple causal indicator chain for assessing the cascading effects of a management action, such as establishment of an MPA, on ecological indicators, the ecosystem services that depend on ecosystem function, and the social values that in turn depend on ecosystems services. Benefit relevant indicators (BRIs) are shown in red circles and represent measurable indices of change in the ecosystem services shown above them. This diagram expands on the original concept to include a feedback loop where changes in values influence willingness to provide reciprocal services to ecosystems to complete the cycle. Adapted using elements from Comberti et al. 2015[65] and Olander et al. 2018[66].

Table 2: Summary of key indicators across four domains (environmental, ecological, social, governance) for MPAs and MPANs along with representative examples of associated parameters. Although this list of potential indicators is not comprehensive and the relevance of each will vary depending on the context, this table can help those embarking on an indicator selection process to identify major gaps in suites of proposed indicators.

Indicator Class	Representative Parameters
A. ENVIRONMENTAL	
Core Oceanographic Parameters	• Current velocities • Temperature • Salinity • Dissolved oxygen (DO) • Seawater chemistry (dissolved inorganic carbon, pH, etc.) • Nutrients (N/P) • Turbidity • Photosynthetically active radiation (PAR) / Primary Productivity
Benthic Structure	• Bathymetry • Substrate type and composition • Organic matter profile
Terrestrial Inputs	• Precipitation and discharge • Freshwater inputs (stable isotope levels and ratios) • Sediment inputs (turbidity)
Coastal Change	• Coastal position • Drivers of coastal change (wind, waves, sea level)

Indicator Class	Representative Parameters
B. ECOLOGICAL	
Species	• Distribution • Abundance (by focal species) • Population structure (size and age structure, by focal species) • Dispersal • Health (disease, damage) • Behaviour • Phenology (life cycle event timing) • Life history traits
Community	• Taxonomic composition • Species Diversity / Richness • Evenness / Dominance / Rarity • Total biomass • Total abundance • Functional diversity • Phylogenetic diversity
Connectivity	• Size & arrangement of MPAs • Population connectivity (physical movement, genetic, demographic) • Ecological process connectivity (trophic linkages, nutrient flows, and energy transfer)
Representation and Replication	• Key biodiversity areas • Key species richness hotspots • Proportion species / ecoregions distribution covered by MPAs

Indicator Class	Representative Parameters
C. SOCIAL	
Livelihoods	• Employment • Income • Job satisfaction • Perceived impacts on livelihoods • Material style of life • Fishing patterns • Poverty • Impacts on business • Number and characteristics of visitors • Knowledge of MPANs
Health and Safety	• Access to food • Food security • Physical health • Emotional and mental health • Disaster preparedness • Sensitivity and adaptive capacity
Culture and identity	• Environmental values • Non-use values • Cultural sites/areas • Cultural practices • Sense of place • Ocean awareness
Social relationships	• Internal relationships • External relationships • Trust • Levels of conflict • Perceptions of wellbeing and equity

Indicator Class	Representative Parameters
D. GOVERNANCE	
Human Activity Pressures	• Levels of existing or changing fishing pressure • Bycatch • Shipping and transportation • Underwater noise • Litter • Contaminants • Spatial distribution of threats
Compliance and Enforcement	• Number of patrols • Level of enforcement • Vessel traffic monitoring (spatial and temporal) • Satisfaction with MPA enforcement • Violations / Non-compliance • Sanctions • Incentives • Attitudes and behaviours toward MPAs
Legal and Administrative Frameworks	• Adequacy of legislation • Existence of a management body • Existence of a management plan
Property rights	• Access rights • Use rights • Management rights • Exclusion rights
Stakeholder participation	• Interaction with stakeholders • Level of stakeholder participation • Level of stakeholder support
Capacity	• Adequate human resources • Training • Reliable funding

Monitoring by volunteer anglers for hook and line surveys, Oregon © ODFW

1.5 Indicator Selection Process

Indicator selection should occur through a systematic, transparent and participatory process that captures the values of affected communities and monitoring partners.[67,68,69,70,71] Collaborative selection of indicators through transparent multi-stakeholder processes—and building on existing monitoring programs—helps to ensure that the indicators selected capture the concerns, values, and voices of diverse communities. This is particularly essential for monitoring programs that will be implemented in partnership with multiple partners and community organizations. Engagement should begin early and continue over a series of meetings or workshops to build mutual understanding and a sense of trust, ownership, and buy-in for monitoring activities. Whenever possible, the collaboration strategy should be co-created with participants to consider the community and cultural context and make use of appropriate engagement and prioritization strategies, particularly when including Indigenous participants (e.g., as described for a process in Haida Gwaii, British Columbia[72,73]). Different participants are also likely to have different indicator preferences based on their relationship to marine areas in the network and the process must allow for time and space to reconcile differences in perspectives and ways of knowing to arrive at a compromise on recommended indicators. An iterative participatory indicator selection process also offers an opportunity to build relationships and share data and ideas that create a foundation for ongoing collaboration for MPA monitoring, management, and reporting moving forward.

- Finding an appropriate approach for indicator selection has been challenging and contested in virtually all cases. California had failed experiences with both expert-driven and stakeholder-defined selection of indicators, and eventually found success through a combined process that involved both stakeholder consultation and expert input.

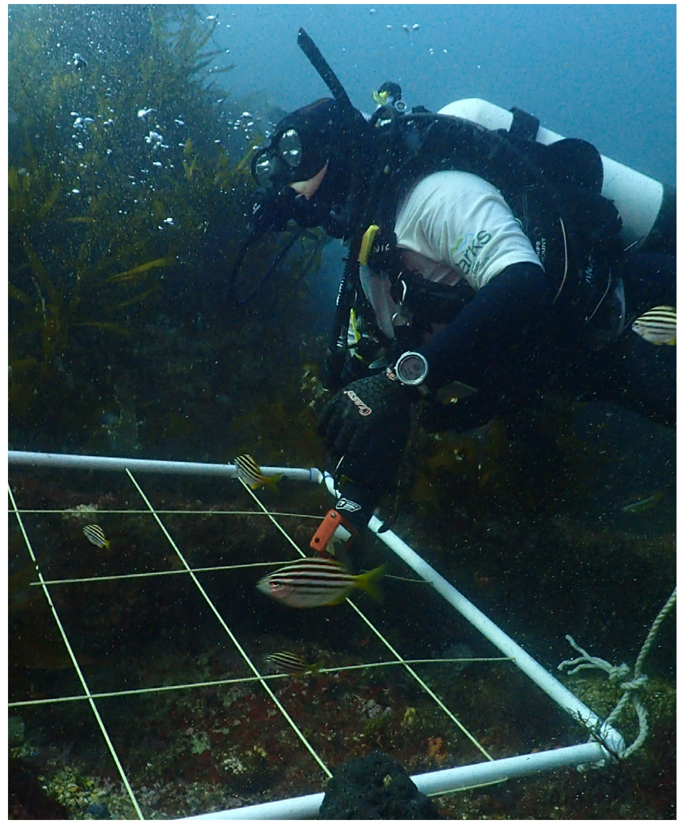
- Oregon made the decision that instead of selecting key social indicators, during the initial 10 years of implementation leading up to the program assessment, they would cast a wide net to detect and describe the different social, economic and cultural impacts that have occurred on regions, communities, social groups, and individuals to get a better understanding who is being impacted and how. After 10 years of research there is now a basic understanding of who is being affected by the marine reserves and how.

Indicator selection criteria should draw clear links between proposed indicators and MPAN management objectives and levers.[74,75,76,77] Ensuring that key indicators and associated monitoring activities are explicitly tied to a clear set of predetermined MPAN management objectives and levers helps to focus MPA monitoring programs and ensure effective use of limited monitoring resources. Without this focus, there is a risk that monitoring programs inadvertently duplicate the efforts of broad status and trends monitoring programs, attempt to monitor too many indicators, spread their resources too thin, and fail to inform decision-making. This outcome can lead to erosion of trust among monitoring partners and disengagement from the monitoring process that contribute to lengthy setbacks and gaps in data collection as issues are gradually resolved. When in doubt, it is generally more efficient to start with a smaller set of indicators, ensure that data collection for these indicators can be implemented effectively, and gradually add more indicators over time. The outcomes of existing regional monitoring programs can help to provide insights on a reasonable starting number of indicators and sites for partners to monitor effectively. When management objectives, management levers, and their key data needs are clearly articulated, selection criteria can be developed to yield indicators and associated research questions and anticipated outcomes (e.g., no change, recovery, reduction) that are useful to management at an MPAN scale.

- In the Australia case study, insights from Victoria's 20-year MPAN monitoring review highlight the importance of explicitly linking indicators to management objectives, thresholds, and triggers for management action to draw a clearer line of sight from management objectives to actions 'on the ground'.

- Aotearoa New Zealand's Marine Monitoring and Reporting Framework (2022) provides national level standards for monitoring protocols. Guidance within the Framework is based on 10 main themes, and within each theme there are recommended methods for data collection, data preparation, analyses, and reporting and communication. The national level guidance is based on the Biodiversity Monitoring and Reporting System and is meant to feed into both broad scale monitoring and provide nationally consistent monitoring across protected areas.

Using complementary "suites of indicators" capturing different types of information within and across social-ecological dimensions can improve confidence in monitoring and assessment outcomes.[78,79,80,81] In many cases, indicators can be bundled into suites of complementary measures rather than being used in isolation. For example, suites of indicators can be used to measure *different aspects of the same attribute*, to mitigate bias or uncertainty in any one indicator. In other cases, suites of indicators are designed to measure *multiple attributes of the same broader system* to better understand relationships and interdependencies between indicators. This latter strategy aims to include indicators from each of the different themes captured in this section (e.g., environmental, ecological, social, governance) to provide a more multidimensional and holistic picture of the effects of MPAs on the broader social-ecological system. Responses that are aligned across multiple indicators can increase confidence in monitoring outcomes, while misalignment can help to clarify causal relationships or identify gaps in monitoring that need to be addressed.



Diver with quadrat for reef survey, Beware Reef, Australia © Parks Victoria

1.6 Data Collection

A decision framework is needed to manage trade-offs between the frequency, spatial coverage, and level of detail of data collection activities across MPANs spanning large geographic areas. For instance, monitoring conducted every year for ten years will be more costly, but provides a larger sample size for establishing status and trends with greater confidence than monitoring conducted only three years out of every ten years. Global case studies and the published literature emphasize the need to be realistic about tradeoffs between amount and resolution of data that can be collected at each individual site.

- California's MPA Monitoring Action Plan chose more intensive yet consistent monitoring at fewer 'sentinel sites' in order to ensure consistent time series for data that enables more extrapolation. The tiered approach to site monitoring has helped to prioritize site selection when funding is insufficient. Additionally, California adopted a partnership-based monitoring approach (e.g., academic institutions, community science programs, and engagement with fisheries) that has helped to leverage supplementary funding and resources.[82,83]

- Australia's Victoria MPAN used a tiered and rotating panel sampling approach, based on power analysis, that sought to balance the ability to control for environmental variability in analyses while also monitoring at a greater number of sentinel sites. In this design, sampling takes place at each site for two consecutive years to better control for interannual variability before rotating to another site in subsequent years, leaving a gap of up to five years (shorter at more variable or higher-risk sites) before the next round of sampling. Detailed sentinel-site monitoring is complemented by Rapid Health Assessment at non-sentinel sites in the network on a more frequent schedule.

Partnerships are critical for effective data collection across large, remote, and diverse MPANs and require data collection methods and strategies that are tailored to partners' needs and capabilities. Diverse partners help to fill gaps in expertise, support scientific success, bolster credibility and political acceptance, and maximize cost-effectiveness, in addition to contributing to long-term data sets for MPAN evaluating.

- California adopted the California Collaborative Approach, MPA Partnership Plan (2014)[84] that outlined how non-governmental partners could be engaged in supporting monitoring. One example is the California Collaborative Fisheries Research Program where fish harvesters, agency scientists, and researchers worked together to address the need for baseline data and carried out long-term monitoring.

- In Australia, parts of Victoria's MPAN monitoring program are carried out in collaboration with partners thanks to funding through the Australian Research Council Linkage Program which actively promotes research partnerships between researchers and government agencies, industry, and community organizations.

- Monitoring of intertidal habitats is particularly well suited to collaborative monitoring with citizen scientists given the accessibility of these habitats. For example, intertidal monitoring in Australia's Victoria MPAN is carried out through the SeaSearch science program, while monitoring of beach litter as part of the UK Marine Strategy is undertaken by volunteers and environmental organizations. Such programs also provide an opportunity for raising awareness, sharing knowledge and contributing to broader social and environmental objectives.

- Oregon found benefit in looking outside of marine institutes to find research partners with expertise in monitoring the human dimensions of natural resources. The majority of academic social science research partners were in departments/schools of Tourism and Recreation, Forestry, Public Policy, Anthropology, and Psychology. Developing long-term collaborations with these researchers has helped establish greater continuity in long-term data sets and ensure that research projects produced meaningful contributions to an applied research and management program.

Planning and decisions related to the methods, tools, technologies, and sampling design strategies that will be used to collect data on indicators about MPAN status, trends, and performance is a key element of designing a MPAN monitoring framework.

- Data on environmental and ecological indicators typically rely on direct observation or sampling (e.g. dive surveys); however, newer methods such as eDNA and remote underwater video stations have greatly facilitated monitoring of the composition and characteristics of local subtidal communities. At the same time, automated monitoring systems (e.g., Smart Buoys) and remote sensing technologies paired with automated data classification algorithms are now enabling monitoring of marine habitats and species (e.g., marine macroalgae, seagrass beds, and marine megafauna via satellite earth observation) and of human activities (e.g., hydrophone arrays and satellite tracking for monitoring marine vessel traffic and compliance with MPA boundaries and other regulations) at broader geographic scales than ever before, which allows for efficient monitoring of entire MPANs (see Environmental Indicators, Ecological Indicators, and Tools and Methods sections of the Supplementary Report for further information for further information about the application of these methods).[85,86,87,88,89]

- Data on social and governance indicators can be collected via different approaches, including secondary datasets for details on income and employment, reviewing policy documents and public records for details on participation, enforcement and compliance, and surveys (some taking advantage of electronic monitoring methods mentioned above), interviews and focus groups to capture the perspectives of stakeholders on a range of different topics[90,91] (see sections on Social and Governance indicators in Supplementary Report for further information about the application of these methods; see also Oregon case study in Supplementary Report).

- Quantitative and qualitative data collected by multiple methods generate insights about the status of indicators and the causal mechanisms that might be driving them, supporting effective adaptive management (see details in Data Collection section of Supplementary Report). There are also opportunities for efficiencies of scale when selecting monitoring methods capable of simultaneously capturing information on multiple indicators (e.g., remote underwater video capturing information on community composition, fish size, and behaviour; remote sensing capturing information on habitat distributions as well as sea surface temperature and productivity across multiple spectral bands). The process of selecting a suite of monitoring tools and methods is typically iterative and initiated alongside the selection of indicators themselves, given that the technical complexity, feasibility, timeliness and cost of monitoring methods are included in most indicator selection criteria.

- The discipline of landscape and seascape ecology provides a useful evidence base and set of analytical tools for effectively monitoring multiscale processes that are one of the distinguishing factors of protected area networks, for example, by using analytical windows of varying dimensions for spatial tuning of sampling units across different habitat types, configurations, and data collection methods.[92,93,94]

Existing and emerging data collection technologies can help to overcome partner capacity constraints for monitoring some indicators. Traditional data collection methods for some indicators are time- and labour-intensive (e.g., dive surveys) or require specialized training and equipment. These present barriers to entry that limit the number of partners able to participate in data collection and thus the overall availability of opportunities for data collection. In contrast, emerging methods such as passive environmental DNA (eDNA) collection can simplify monitoring of species presence or absence and community composition via surface-based sampling throughout the water column that can yield some of the same information previously only accessible by subtidal dive surveys,[95,96,97,98] although it can not yet yield information on other indicators such as abundance. Similarly, satellite remote sensing and electronic vessel monitoring can more efficiently collect data previously only accessible via time and resource-intensive shore-based or aerial overflight surveys.[99] Furthermore, these newer approaches can be paired with traditional surveys to help draw inferences and allow for improved assessments. Though these methods may be simpler to implement, they can also yield large amounts of complex data that can require dedicated data management and storage solutions and may be more difficult to process and analyze, which only delays the need for additional technical capacity to later stages of the monitoring workflow.

- New technologies for marine monitoring and assessment are emerging rapidly providing opportunities for real-time and/or lower cost monitoring of certain indicators. The UK Marine Strategy is, for example, increasingly exploiting SmartBuoys, benthic landers and remote sensing to monitor eutrophication and related indicators. Over time these approaches may help to improve or potentially replace more costly and time-intensive monitoring approaches.

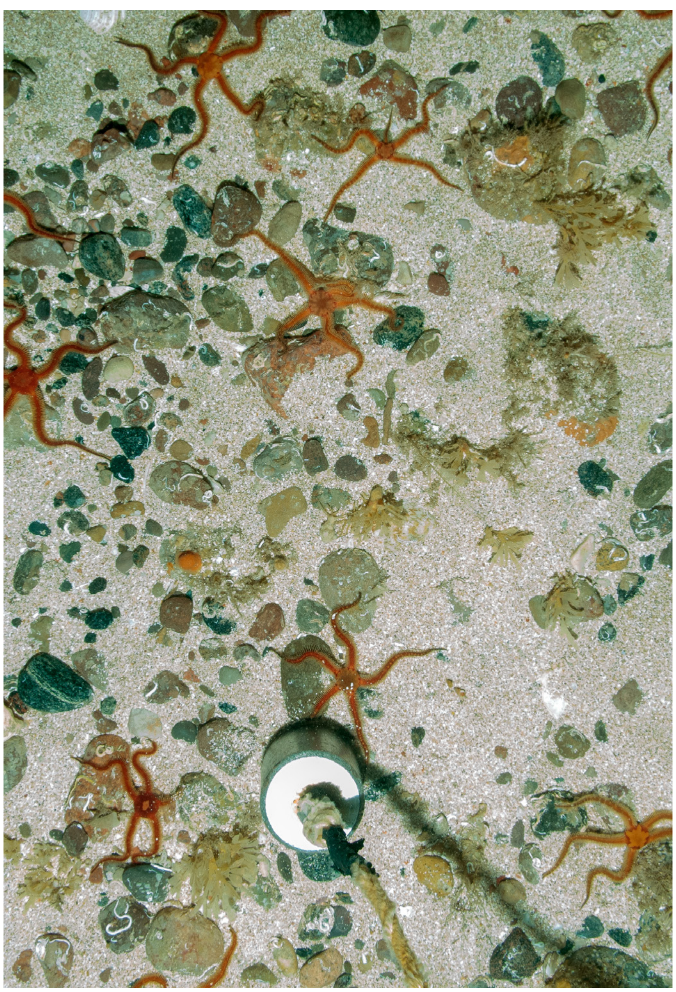
- In Victoria, Australia, monitoring program reviews include consideration of tools and technologies including Baited Remote Underwater Video and how they may best complement or replace historical methods. This process can be facilitated by early and ongoing pilot testing of emerging methods to provide the information necessary for evaluating the inclusion of new methods.

The selection of data collection tools, methods, and strategies must consider alignment with local and Indigenous science methods and practices, particularly when these communities will be partners in monitoring. Many data collection strategies designed from the starting point of a Western science worldview fail to account for the ways of knowing, historical and contemporary practices, and capacity limitations of local community monitoring partners in ways that ultimately constrain the overall program's ability to gather information relevant to decision-making. It is preferable to co-develop data collection methods that start by understanding how community monitoring partners already interact with marine areas and resources and build data collection into those existing practices to help uphold cultural continuity, improve the overall efficiency of data collection programs, and increase the likelihood that they can be sustained over time in spite of turnover in technical staff.[100,101,102,103]

- While yet to be implemented, Aotearoa New Zealand's Marine Monitoring and Reporting Framework (2022) describes the importance of Indigenous treaty partners' ability to exercise their full roles as rangatira (leaders) and kaitiaki (guardians or caretakers). Rather than specifying criteria for measuring success towards this outcome, the Framework states that such outcomes can only be assessed by Indigenous partners. Further, the Framework specifies that the government should work closely with Indigenous partners and ensure that they have necessary resources for participation.

When coordinating data collection across many partners, the monitoring programs must consider variation and complementarity of tools, methods, indicators, and scales employed by different partners. Although standardization of indicators and methods is one approach to coordinating monitoring efforts, this can be challenging to achieve across all indicators while also seeking to leverage and maintain continuity with existing monitoring initiatives.[104] Many MPAs and MPANs have issued standard monitoring and evaluation protocols to meet this need (e.g., for Australia in Przeslawski et al. 2019[105], and New Zealand in New Zealand Government 2022[106]), while additional best practices for standardization are also being developed for emerging monitoring technologies (e.g., eDNA in Shea et al. 2023[107] and underwater video monitoring in Pelletier et al. 2021[108]) and marine data management workflows.[109,110,111] Insights from distributed community monitoring networks in other contexts suggest that a combination of standardized core (common) indicators and methods used across the region of interest coupled with additional indicators that are meaningful in a local context can address gaps in knowledge and meet the needs of those engaged in site- and regional-scale management and decision-making.[112] It is also possible to implement standardization at the data management and analysis stage for methods that have different biases and trade-offs by applying correction factors (e.g., for known differences in selectivity and detection probabilities) when aggregating data.[113]

Successfully interpreting the data emerging from MPA monitoring programs to draw valid inferences about MPA effectiveness depends on a robust sampling design that accounts for the constraints of field logistics. This is particularly relevant for the remote and difficult context of MPANs composed of multiple sites that vary in their characteristics, environmental conditions, and confounding variables. Monitoring strategies should strive to achieve spatially balanced and randomized sampling designs, which are considered to be the gold standard for controlling confounding factors and establishing causal relationships for MPA performance that are most informative for management. However, there is broad recognition that the conditions required for such designs are often violated by unpredictable weather, equipment failure, and other constraints of field logistics. In light of this reality, monitoring strategies should plan for the eventuality of unbalanced sampling and uncontrolled confounding factors by applying more sophisticated statistical methods (e.g., generalized linear mixed effects models with spatial and spatiotemporal random fields) that are capable of making robust inferences despite these irregularities[114,115,116] (see Victoria (Australia) case study in Supplementary Report).



Benthic monitoring © Joint Nature Conservation Committee/Marine Scotland Science

1.7 Data Management

MPAN data management practices should be designed to ensure that data collected by and for partners and stakeholders is Findable, Accessible, Interoperable and Reusable (FAIR). Where possible, data should be easy to find with clear, accurate, and complete metadata, with unambiguous and consistent licensing and usage rights that allow for reuse and redistribution, that can be easily integrated with other data sources and tools and preserved over time to allow for its reuse by others.

- The UK is currently working towards the development and implementation of a data strategy for the UK marine monitoring and assessment strategy community, and has already established resources for storing and sharing data through the Marine Environmental Data and Information Network.

Data management plans related to information about Indigenous communities and Indigenous knowledge should be co-developed with partners to ensure adherence to principles of information governance. In general these include developing guidelines to ensure the rights of Indigenous Peoples to own, control, access and possess (OCAP) data that are collected by and/or about Indigenous Peoples, and ensuring that data helps to advance Indigenous innovation and self-determination through adherence to CARE Principles for Indigenous Data Governance (Collective Benefit, Authority to Control, Responsibility, and Ethics).

Development of data sharing agreements should be initiated as early as possible. Negotiations for data sharing can take many years as they are based on strong relationships and trust. All partners will need to know each others' intentions and motivations for information use, and may need to revisit these agreements over time if the monitoring context changes. Among other things, these agreements should specify the level of acceptable data aggregation or other measures needed to obscure sensitive data that may be otherwise revealed as part of the monitoring and reporting process.

1.8 Analyses and Evaluation

Data collected through monitoring programs must be translated into meaningful information on change in the status and trends of indicators to enable performance evaluation of MPAs and the MPANs to which they belong. By their very nature, the evaluation of MPANs also requires analysis and reporting at multiple scales to assess whether design features such as representation and connectivity are being achieved. This means evaluating whether and how key response indicators across the network are changing with respect to those design features and MPAN goals.

- As part of California's decadal review, Caselle et al. (2022)[117] reported on the ecological performance of the network, as well as habitats, climate resilience, and human engagement. The analysis used monitoring data to evaluate MPA performance evaluation questions from the MPA Monitoring Action Plan as well as the recommendations of both the Decadal Evaluation and the Climate Resilience Working Groups.

- The UK publishes an update to the UK Marine Strategy every six years that provides a high-level assessment of progress towards Good Environmental Status using monitoring data across 11 core descriptors, including biological diversity, fisheries, foodwebs, habitats, and eutrophication across all UK waters, and highlights what further actions are required to achieve objectives.

Translating monitoring data to indicator outcomes typically requires the integrated use of a broad range of analytical tools of varying complexity. For simple indicators, the use of summary statistics, hypothesis testing, correlation, and time-series trend analysis may be sufficient. For more complex indicators related to the emergent properties of networks, monitoring data may be used as inputs to quantitative models that predict the status and trends of certain indicators and potentially project them forward through time to generate testable hypotheses. Many of these tools are the same ones originally used in MPAN planning, but are updated with new data collected following MPA establishment in an iterative cycle where new empirical monitoring data validates and improves models. The integration of data with a broad toolbox of statistical and dynamic models is particularly important for the evaluation of MPAN processes and outcomes, such as connectivity and cause-effect pathways across social-ecological systems, which are operating at broader spatial and temporal scales and resolutions that would be difficult to evaluate through direct monitoring alone[118,119] (see section on Analyses and Evaluation in the Supplementary Report). In addition to quantitatively oriented data and indicators, it is also important to consider the use of qualitative indicators that can report on the status of values of interest in ways that may be more accessible to broader audiences (e.g., 'vital signs' or 'state of the ocean' types of reports).

Aggregation of monitoring data across scales and programs needed to measure simple or multi-metric indicators must account for variation in data scale, continuity, and collection methods to maintain the validity and reliability of assessments and evaluation outcomes. Data interoperability and aggregation should be considered in the earliest stages of MPAN monitoring design to facilitate future data aggregation and help to increase accessibility and use of the resulting data outputs for evidence-based decision-making. As with data collection, the development of standardized, semi-automated, and well-documented data integration workflows can greatly facilitate ongoing and reproducible MPA monitoring data integration at large scales (see section on Analyses and Evaluation in the Supplementary Report). Importantly, aggregation must also take into account issues of data sensitivity, privacy, and sovereignty, particularly with respect to data collected by or about Indigenous communities. This is in addition to cultural and community protocols that influence how communities may want their knowledge and data aggregated and shared. This may require aggregation of finer-scale sampling data at coarser scales to protect the locations of sensitive sites that would be revealed at smaller scales, and additional effort to reconcile rescaled data with other relevant datasets to maintain a fair representation of the data based on monitoring effort[120] (see section on Data Management in Supplementary Report).

Many MPAN analysis and evaluation tools make assumptions associated with a degree of uncertainty that should be quantified, acknowledged, and communicated as caveats when reporting evaluation outcomes (see section on Analyses and Evaluations in Supplementary Report for more detail). Common assumptions of analyses used in MPA evaluation may include homogenous age structures or larval distributions, endpoints reflecting long-term steady state rather than short-term variability, omission of bioenergetics or evolutionary adaptation, and assuming linear responses to stressors when other response dynamics are possible.[121] When faced with multiple sources of evidence and uncertainty about the relative weight of evidence of each of those sources, different frameworks can be used to evaluate the amount, quality, and consensus of evidence overall. The adoption of practices such as these in reporting results from the analysis of monitoring data helps readers interpret findings, avoids overstating inferences, builds credibility and confidence in decision-making, and enables the identification of research priorities to help explicitly reduce these uncertainties in the future.[122]

Capacity for data management and analysis can be a limiting factor in distributed monitoring programs involving multiple partners. This barrier can be overcome with training and capacity-strengthening activities to establish dedicated capacity for analyzing MPA monitoring data. There is also growing interest in the use of digital data entry (e.g., using mobile apps and tablets) as well as standardized automated scripts, workflows, and intuitive web-based platforms and software to streamline this process. These approaches could help to further reduce barriers to analysis within the communities collecting monitoring data and increase the potential for rapidly processing MPA monitoring data to generate more timely results needed for evidence-based decision-making.

- In one 15-year retrospective of lessons learned from a global MPA effectiveness monitoring program, the development of standardized monitoring protocols and data management procedures, a user-friendly online interface for indicator analysis, and interactive dashboards of indicators were cited by participants as among the most valued practical outcomes.[123]

Vibrant nudibranch © Joint Nature Conservation Committee/Marine Scotland Science

1.9 Communications and Reporting

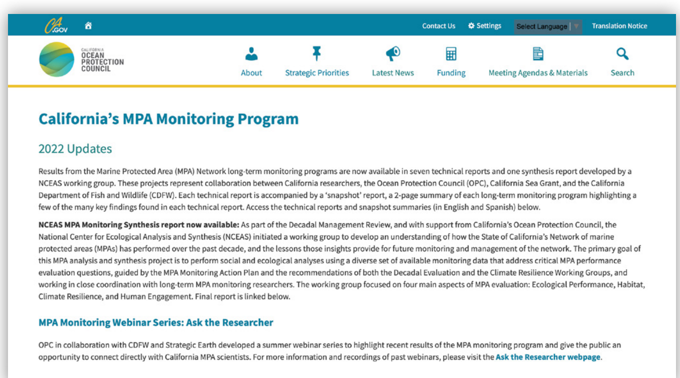
It is important to set and communicate realistic expectations of MPAN outcomes for partners who are involved in decision-making for adaptive management. Although it is possible for certain species to respond positively to the establishment of a protected area, evidence has shown that in the short term it is equally possible for species to show no change, or to decrease in abundance or distribution. Simulation models can play a critical role in projecting likely timelines for recovery based on an understanding of species biology, baseline ecosystem context, and specific management scenarios in order to set these expectations.[124] Setting realistic expectations about these timelines should play a role in evaluating whether a MPAN is meeting its goals, thus informing the adaptive management process.

- Patience is needed for observing long-term positive MPAN outcomes. California has completed its first decadal review, showing that decision-making from existing data is still premature. Some adjustments have been made to management plans (e.g., MPA boundary changes) but deeper shifts in management approach have not yet taken place (e.g., no changes to MPAN goals).

Public communication and education influence perceptions about the success and importance of MPANs. Communications during the establishment of a MPAN are often couched in positive outcomes for ecosystems and people, leading to high expectations for tangible positive outcomes. Best practices for communications related to MPAN monitoring include having a plan for public engagement and education that includes expectations for the timeline and magnitude of anticipated outcomes, as influenced by factors such as prior harvest pressure, natural recruitment variation, and others.[124] Because many aspects of MPAN performance on multiple indicators will be assessed using technical methods including genomics, remote sensing algorithms, and quantitative modelling, effective science communication techniques will be critical for distilling key outcomes into messages and formats accessible to broad audiences, including communities, monitoring partners, and policy-makers. Many MPAs and MPANs are adopting the use of visual reporting methods such as MPA report cards, interactive infographics, and multimedia StoryMaps for more accessible reporting. As it is imperative to ensure ongoing public support for an MPAN, a public engagement and communications plan is an essential element of broader monitoring and evaluation plans.

- The UK Strategy publishes a report and online resources summarizing progress towards Good Environmental Status across several indicators every six years. At the highest or coarsest level the status (achieved, partially achieved, not achieved) and trends (improving, stable, declining) of these indicators are reported across the UK, with links to more granular reports for those that might be interested.

- California's MPA Monitoring Program hosts a web page that links stakeholders to information about monitoring. The information includes summaries and technical reports that cover a variety of topics, including California Collaborative Fisheries Research Program and monitoring of human dimensions, estuaries, kelp, and other key habitats.



- The Oregon Department of Fish and Wildlife (ODFW) found that communicating the results of their human dimension research projects has helped bring a voice to people who are impacted by MPAs. For example, sharing stories and perspectives from people who perceive themselves to be negatively impacted either economically or socially by MPAs has been very important to helping build trust within the fishing community. These types of research uncover impacts that would otherwise not be detected by other research methods and provide a way for individuals or small groups of people to share their lived experience and feel heard. Additionally, this type of research and reporting has helped to build trust that ODFW is fulfilling its mandate, that the science being produced by ODFW and partners is rigorous and robust, and that ODFW is a trusted source of information.

A reporting schedule creates accountability and informs regular reviews. As far as the broader public is concerned, if they haven't heard about something, it isn't happening. Prior experience has shown that regular reporting about progress on MPAN implementation and monitoring is essential for maintaining public trust in the process and its intended outcomes. Requirements for regularly scheduled reporting (e.g., at monthly or 1, 5, and 10 year intervals depending on the nature of reporting) provide a basis for reflection on monitoring challenges, successes, and outcomes. Shorter intervals can be more important in the early stages of MPAN and monitoring system establishment when co-development activities are occurring, things are evolving rapidly, and minor adjustments may be made more frequently. In contrast, decadal reviews allow sufficient time to pass to observe some ecological response and provide a critical opportunity for reflection on process and outcomes to date to allow for deeper consideration of broader programmatic changes, if needed, in support of adaptive management. All of this points to the need for communications and reporting to have dedicated long-term funding and support.

Diver with banner, Blue Caverns Onshore State Marine Conservation Area, California
© Amanda Van Diggelen/CDFW

- In the UK, regular reporting mandates have supported assessments that contribute to adaptive management. National governments and agencies in the UK are required to complete an assessment of progress towards Good Environmental Status across each of the 11 descriptors outlined in the UK Marine Strategy every six years and report the program of measures that are used to maintain or improve the conditions of the marine environment. Collectively these requirements provide an important foundation for adaptive management by ensuring that data are available to managers and stakeholders to inform decision-making and public consultations.

1.10 Pathways to Management Decisions

As much as possible, it is beneficial to design monitoring and evaluation programs to enable managers and governing partners to quickly identify knowledge gaps and emerging threats and develop plans for addressing them. Monitoring and evaluation of MPANs serve several critically important functions, including enabling adaptive management that responds to social and ecological feedbacks.

- In Victoria, Australia, a rigorous adaptive management approach is applied to MPAN monitoring programs themselves. These programs are subject to periodic review and reassessment using a structured prioritization framework to ensure management relevance, technical rigor, cost-efficiency, and adoption of emerging global best practices. The monitoring program review is a multitiered process that can apply to individual monitoring components and programs (e.g., the fish community monitoring component of the subtidal monitoring program) as well as the broader MPAN monitoring enterprise in which they are embedded.

Devising monitoring objectives that are based directly on MPAN objectives can facilitate future decision-making. Although it can be tempting to attempt to collect all possible information, it is important to find efficiencies for data collection. To this end, establishing clear links between indicators, monitoring questions, and MPAN objectives can facilitate logical management levers (Figure 1).

- California's decadal review has led to multiple reports showing the benefits of iteratively refining management objectives and questions.[125,126]

Focus on monitoring indicators relevant to management within and outside the network. Examples of key considerations include indicators that inform the potential need to change regulations for allowable activities within MPAs, changing zoning within MPAs, changing the boundaries of MPAs, establishing new MPAs within the network, conducting restoration at single or multiple sites (e.g., to facilitate connectivity), or increasing compliance, enforcement, or outreach strategies. Changes observed within the network can also inform decision-making by regulatory authorities beyond the network. For example, monitoring outcomes for water quality within MPAs may be influenced by land use management practices adjacent to MPA sites. Similarly, outcomes for fish population recovery and spillover may be influenced by changes in fishing behaviour outside MPA boundaries, while MPAs can in turn influence spatial patterns of population structure in ways that violate the assumptions of traditional stock assessment and fisheries management frameworks and may warrant modifications.[127]

- The MPAN adaptive management process in California has led to several legislative and regulatory amendments.[128] Legislative amendments have included increased flexibility for wildlife enforcement officers to cite recreational MPA violations (Assembly Bill 298, 2015) as well as changes to penalties for illegal commercial fisheries violations (Assembly Bill 2369, 2018). This process also led to recommendations for designing monitoring programs that can inform MPA performance and evaluation as well as traditional fisheries management for managed resources.

Predicting alternative management outcomes to which monitoring data can be compared enables a more rigorous and proactive approach to evaluation of MPA effectiveness and adaptive management. Active adaptive management requires prediction of alternative expected management outcomes linked to MPA management objectives against which monitoring data can be compared to understand the most likely contributing factors for observed outcomes or identify unexplained gaps between predictions and reality, hinting at unknown drivers.[129] The use of expert judgment, life history information, data, and models to generate alternative predictions provides an opportunity to investigate observed changes and to explore potential changes that are plausible but have yet to occur.[130,131] Where uncertainty remains, management experiments (e.g., changes to timing of allowable extractive activities within partially protected MPAs) and associated adjustments to sampling designs (e.g., monitoring additional sites, time periods, or covariates where the experimental intervention is most practical, monitoring additional covariates that may influence success of the intervention, etc.) can create additional contrast in the data to better tease apart these drivers and identify the factors impeding desired outcomes and inform iterative adjustments to future management and monitoring strategies.[132]

Importantly, factors that are known to influence MPA performance (e.g., variations in past fishing pressure, recruitment rates, species life histories, length of protection, and external pressures such as land-based pollution) should be explicitly accounted for in forward-looking models used to make predictions.[133]

- The California experience showed that the amount of fishing pressure that occurred before implementation of MPAs, as well as the duration that an area has been under protection, strongly influence observable outcomes.[134] Species that were more heavily fished were more likely to respond quickly to conservation measures. The important implication from these insights is that long time series (i.e., longer than 10 years) are required to directly observe meaningful changes for most species.

Marine life on subtidal surveys © Joint Nature Conservation Committee/ Marine Scotland Science

Although testing management hypotheses using experimental designs can be challenging within an MPA context, applying controls, randomization, and other sampling principles to the design of monitoring for human activities can support more scientifically sound and efficient management outcomes.[135] This might mean identifying those activities for which evidence of impacts are lacking and determining which are most amenable to manipulation in collaboration with affected marine users or communities to help reduce uncertainties.[136] As additional data are collected, predictive models can be updated to update expectations about MPA outcomes and generate new testable management hypotheses for ongoing adaptive management.[137]

Adaptive management is generally enabled from the adoption of objectives that are specific, measurable, achievable, relevant, and time-bound (SMART). Adherence to the general principles of SMART objectives may facilitate adaptive management in a variety of different ways. (see section on Pathways to Management Decisions in Supplementary Report for further details).

Clam bed monitoring, Vancouver Island, British Columbia © Markus Thompson

Part 2: Recommendations for Planning and Operationalizing Monitoring for the Northern Shelf Bioregion MPAN

Introduction to the Northern Shelf Bioregion MPAN

The Northern Shelf Bioregion (NSB), also known as the Great Bear Sea, covers more than 102,000 km^2 from North Vancouver Island to Alaska (Figure 4) and encompasses a diverse mosaic of marine ecosystems including open ocean, deep sea ecosystems, seamounts, fjords, rocky reefs, coral and sponge reefs, nearshore kelp forests and eelgrass beds, and estuaries. An oceanographic transition zone between major ocean currents generates significant upwellings and strong tidal mixing that supplies a steady stream of nutrients from both deep-sea sources and watershed inputs across the region's complex coastline. These conditions support high productivity as well as habitat and species diversity, with the region well known for extensive canopy kelp forests, seabird colonies, and marine mammal populations, including sea otters recovering from near-extirpation by the fur trade. This ecological bounty has supported First Nations communities, cultures, and commerce since time immemorial, and continues to be a foundation of the region's marine economy through fishing, seaweed harvesting, and tourism, among other activities.

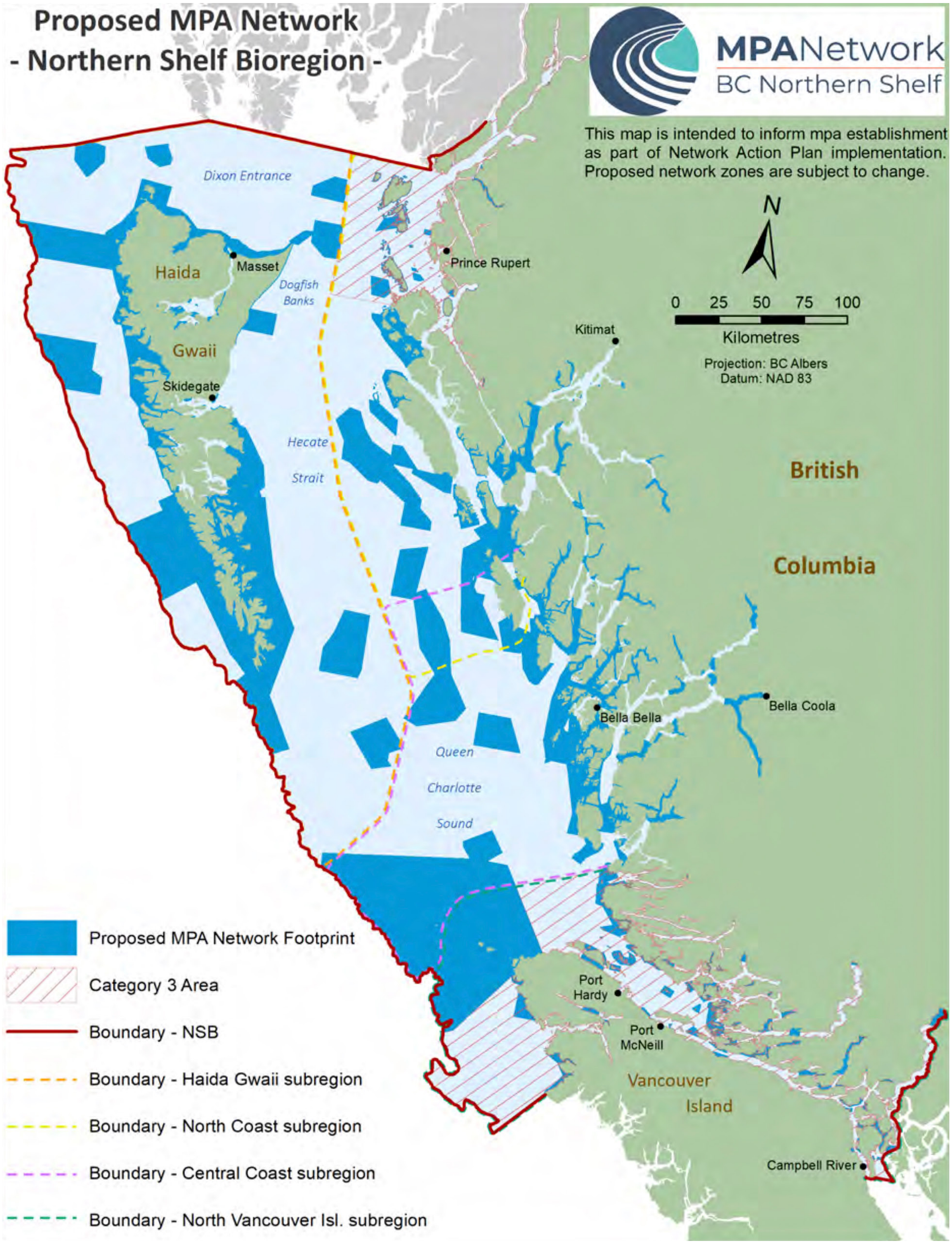


Figure 4: Map of the MPAN for the Northern Shelf Bioregion showing proposed footprint in blue and subregions. Note that this network footprint includes some existing protected areas (source: Network Action Plan 2023[138]).

Eagle standing watch, Haida Gwaii, British Columbia © Markus Thompson

This region encompasses a diversity of marine conservation and management areas established and managed through various mechanisms. This group of marine protected areas will soon be expanded to establish the Northern Shelf Bioregion MPAN to strengthen ecologically-meaningful marine protections with the goal of maintaining or improving ecological diversity and function for generations to come (Figure 4).

Planning for the MPAN has involved long-term visioning and commitment among 15 First Nations governments along with Government of Canada and Province of British Columbia that is summarized in a Network Action Plan (NAP)[139] and its supporting compendia[140,141,142]. The NAP and its three compendiums will help guide implementation of the network beginning in 2025 with six overarching goals that cover both MPAN ecological and human dimensions:

1. To protect and maintain marine biodiversity, ecological representation and special natural features.

2. To contribute to the conservation and protection of fishery resources and their habitats.

3. To maintain and facilitate opportunities for tourism and recreation.

4. To contribute to social, community and economic certainty and stability.

5. To conserve and protect traditional use, cultural heritage and archaeological resources.

6. To provide opportunities for scientific research, education and awareness.

While the formally endorsed NAP included three compendiums, a fourth draft compendium concerns monitoring. This compendium suggests six 'core elements' as part of a successful monitoring program:

- Partnerships
- Indigenous and local knowledge
- Linking monitoring to management
- Attention to climate change
- Sustained funding dedicated capacity
- Standardized data collection and long-term data management

The findings of this report support these core elements. In particular, the emphasis on partnerships and the importance of Indigenous and local knowledge were key lessons in the Aotearoa New Zealand and Oregon case studies. However, both California's decadal review and Australia's 20-year review noted the lack of engagement with Indigenous Peoples as a shortcoming for MPAN monitoring implementation and recommended improved relationships and future collaboration. Partnerships with and among First Nations, coastal communities, and others in the NSB will be essential for effective MPAN monitoring (e.g., via First Nations stewardship programs and academic, NGO, and industry partnerships).

Any new monitoring activities or programs established in service of the NSB MPAN will encounter many of the same challenges facing existing monitoring programs in the region. The vast geographic scale of this sparsely-populated region challenges access to more remote MPA sites, which is further complicated by limited low-tide windows needed for some forms of monitoring as well as unpredictable and often inclement weather. While nearshore sites close to communities are often monitored by First Nations' Guardian programs, these programs face increasing constraints due to rising operational costs, limited and sporadic funding, difficult working conditions, and local housing shortages. All of these issues contribute to challenges in recruiting and retaining qualified staff, which in turn affects the quality and continuity of monitoring activities. For example, many stewardship offices or research programs in the NSB do not carry out underwater monitoring surveys on subtidal ecosystems because of the expense of dive training, the lack of qualified scientific divers and dive equipment, and/or because such resources are already fully committed to species at risk or fisheries-related monitoring programs. Offshore and deepwater sites beyond the reach of local communities are typically monitored by federal agencies through ongoing monitoring programs operated from research vessels as well as stationary underwater sensors and observatories. While these programs are able to access a wider range of sites, they face similar constraints from rising operational costs, competing priorities, and limited ship time that would make it impractical to visit each MPA site in the network each year.

Even when data collection activities are successful, further challenges arise in translating data into information to be used for decision-making. For example, a lack of capacity for data management and analysis within many communities can lead to bottlenecks and lags in data processing that undermine the utility of monitoring for evidence-based decisions. These types of capacity shortfalls have been shown to hinder the performance of marine protected areas across the globe.[143]

Considering the many complexities of the NSB region, the following section draws together key insights from our review of lessons learned from prior MPAN monitoring efforts (Part 1 of this report) to be considered in the development of a monitoring plan for the NSB MPAN.

Vibrant reef life, Gods Pocket Marine Provincial Park, British Columbia © Markus Thompson

2.1 Recommendations for Early Stages of MPAN Implementation

R1. Tie legislative or regulatory drivers for monitoring to a commitment of secure, long-term funding

- As experienced in other jurisdictions, MPAN monitoring is most effective when politically mandated and *publicly funded*. Secured public funding for monitoring demonstrates government commitment to the network and enables year-to-year budgeting and planning. For example, although there was variability in annual funding in both California and Oregon, core state funding ensured a consistent base level of monitoring. Core public funding to support monitoring has also helped MPAN partners to leverage supplementary funding and resources. Biannual or multi-year funding can provide a greater certainty for working with academic partners, who may also secure additional grant funding.

R2. Mandate monitoring and evaluation of the MPAN, not just of individual protected areas

- It is important to evaluate the extent to which ecological and human dimensions goals are being met at the network-level. Monitoring and reporting for individual protected areas and sub-regions can also address site-specific questions as well. However, a mandate or legally-binding commitment for network-level monitoring is essential for evaluating network-level performance, anticipated outcomes, and their time frames.

R3. Support First Nations in ways that ensure Indigenous Peoples and their knowledge systems play a central role in all aspects of MPAN monitoring design, collection, and analysis

- The long-standing relationships of Indigenous Peoples with their ancestral territories is inextricably linked to a tradition of careful observation and stewardship of their lands, waters, and non-human relatives. In the NSB, First Nations communities are engaged in the ongoing monitoring of marine ecosystems through both informal observations during harvesting and other marine use practices[144,145] as well as through formal Indigenous-led monitoring programs implemented by local stewardship offices to inform self-determined environmental management. These First Nations are thus uniquely positioned to play a central role in monitoring the NSB MPAN. It will be important to consider the adoption of a framework to help guide the weaving of Indigenous and western knowledge (e.g. Two-Eyed Seeing or ethical spaces[146]) as well as practical operational guidance for mobilizing Indigenous knowledge in the management process.[147]

- The MPAN case studies revealed heavy reliance on Western scientific methods and very little engagement with Indigenous people and their knowledge throughout the establishment and implementation of monitoring programs. Aotearoa New Zealand is taking strong steps in this direction but the process is at an early stage in an MPAN context. California and Victoria, Australia, have acknowledged their shortcomings and are taking steps to build relationships with Indigenous people, while also drawing inspiration from Indigenous Guardians programs in Canada and elsewhere. There is opportunity for the NSB MPAN process to show global leadership by including First Nations as co-governance partners involved, from the outset, in the design and implementation of monitoring programs.

- The NSB MPAN has already demonstrated leadership by including Cultural Conservation Priorities based on Indigenous knowledge into network design (NAP 2023, Compendium 2). There is an opportunity to build on this foundation and the work of the Nations to lead in the design of a monitoring program that is guided by Indigenous knowledge. These efforts require that trust is built and that Indigenous knowledge systems are honoured. Further opportunities for weaving Indigenous knowledge, science, and practice are identified throughout the recommendations that follow.

- Importantly, many Indigenous communities and programs that may wish to engage in these efforts are already overcommitted to other initiatives. Additional engagement will thus require concerted efforts to reduce structural barriers to engagement, including flexible funding models that help Indigenous communities attract, build, and retain personnel. Engagement will also require capacity building by offering training, competitive wages, stable employment, and opportunities for advancement while also addressing broader issues such as housing.

R4. Engage diverse partners and organizations in the process of MPAN monitoring design as early as possible to build mutual understanding, relationships, and support for ongoing collaboration

- The case studies for existing MPANs reveal that successful monitoring programs are enabled by diverse partnerships (e.g., academia, tribal groups, volunteer scientist groups, industry, ocean technology, etc.). The NSB is a large region and will benefit from mutually agreed upon partnerships and collaborations to increase monitoring capacity. The suggestions below represent a small sample of potential partnerships to pursue:

  » ***First Nations Guardians, programs, and networks*** will likely be key players in MPAN monitoring implementation. Interviews with practitioners and knowledge holders stress that explicit effort is needed to engage with Indigenous stewardship program leads and Guardians beginning in the early stages of monitoring design to draw on their knowledge and experiences and to foster a sense of ownership and commitment to data collection by First Nations. Funding will be required to enable Guardians to do this work.

  » ***Academic partnerships*** should be leveraged to fulfill specific monitoring needs. In all case studies, elements of monitoring were led through academic or research partnerships with university researchers or research institutes. To support these partnerships, a MPAN coordinator should facilitate relationships, support funding arrangements, and ensure good planning and integration of monitoring data and outputs. Furthermore, multiple case studies emphasized the importance of having a team of science advisors providing input into monitoring outcomes, identifying monitoring gaps, and identifying collaboration opportunities. Academic research can also help identify unexpected outcomes from MPAN implementation, including places or phenomena that are outside of planned monitoring that may need consideration.

  » ***Industry partnerships*** in other MPANs have led to successful monitoring outputs and have created buy-in and greater transparency of the effectiveness of MPAs. Exploring ways that commercial fishers, recreational fishers, tour operators, and marine transportation operators could support ecological and environmental sampling inside/outside MPAs can expand sampling efforts. Importantly, monitoring through industry partnerships may require adjustments to standard operating procedures to ensure non-destructive monitoring activities within MPA boundaries (e.g., catch and release practices by recreational fishers assisting with monitoring inside MPAs, as in the California Collaborative Fisheries Research Program).

  » ***Ocean science and innovation hubs*** that are becoming increasingly common as part of a broader Canadian Blue Economy Strategy have the potential to broker partnerships with industry and provide technical and capacity support for the innovation, testing, and operationalization of existing and emerging electronic ocean monitoring technologies, software, and associated data management systems in the NSB MPAN. Key hubs to pay attention to include the Hakai Institute, Ocean Networks Canada, the Centre for Ocean Applied Sustainable Technologies (COAST), and Canada's Ocean Supercluster.

R5. Clearly articulate key MPAN management objectives, levers, and triggers and identify monitoring questions and associated data needed to support decision-making processes for these levers

- **Management objectives** in the NAP are currently high-level and not specific enough to tie to management levers. They should be operationalized to span all dimensions of the social-ecological system and may also be conditional based on the starting condition and anticipated response of different MPA sites being monitored. For example, MPAs in areas considered to be in healthy condition with little history of human pressures may have objectives defined based on maintaining current conditions, whereas MPAs at sites with a prior history of heavy exploitation may have objectives that reflect a desire to improve from current conditions to those at healthy reference sites.[148,149] In both cases, change following MPA establishment is expected only if human uses inside and outside MPAs differ from each other, and MPAs with different starting conditions may require different data collection strategies to monitor effectiveness for their specific objectives.

- **Management levers** should encompass a variety of management pathways, including informal, formal, voluntary, and mandatory measures as well as considering management of both the MPAN itself and of external influencing factors (e.g., fisheries, pollution, land use management at adjacent sites, cross-jurisdictional issues, etc.) to increase the flexibility of management responses to different monitoring outcomes and contexts for achieving management objectives.

- **Management benchmarks** are established to signal unacceptable states of a given indicator and trigger management actions based on a combination of evidence and value judgements about what is considered unacceptable. Benchmarks can be informed by a variety of methods, including baseline data from past scientific surveys (e.g., based on prior surveys of density or productivity in Australia in Howe et al. 2022[150] or Atlantic Canada, DFO 2018[151]), historical records reaching farther back in time (e.g, historical nautical charts showing the past distributions of kelp forests across British Columbia in the 1800s and 1900s[152]), or through the elicitation of local and Indigenous knowledge on the past state of these indicators reaching back from lived experience into oral histories passed down by recent and ancient ancestors (e.g., historical baselines of fish length on the Central Coast of British Columbia[153]).

- **Predicted response times for alternative outcomes** should be estimated for each management objective and key indicator, both of which may vary with a site's initial conditions and characteristics, to test hypotheses about the factors contributing to outcomes and support 'active' adaptive management. Predicted response times can be estimated qualitatively through expert judgment or life history information for focal species or quantitatively using data and models.[154,155] Importantly, predictive models should explicitly account for factors known to influence MPA performance (e.g., variation between sites in past fishing pressure, recruitment rates, species life histories, and duration of protection).[156]

R6. Link monitoring objectives to management objectives and their management levers

- Design monitoring plans to address specific MPAN management questions and inform adaptive management (see section on Pathways to Management Decisions in Supplementary Report). This type of causal linkage can help to ensure that all data collection is being carried out with a purpose for wise use of limited resources.

- Case studies and literature suggest that MPAN monitoring programs have been challenged to influence management because they are established primarily based on rationales about key indicators of interest to monitoring partners, rather than to directly feed into explicit management mechanisms (e.g., via establishing thresholds or triggers for management actions). There is an opportunity for the NSB to set a new precedent for designing elements of the MPAN monitoring that explicitly feed into adaptive management.

R7. Adopt a linked social-ecological approach that can feed into adaptive management

- Integrated social and ecological monitoring of the MPAN provides an important foundation for long-term adaptive management by allowing managers and partners to trace the drivers and impacts of change across social, governance, and ecological systems. For example, how do changes in ecological parameters affect livelihoods? How do policies influence human activities and environmental conditions? This kind of integrated monitoring can be achieved through diverse indicator portfolios, causal indicator chains, and the use of biocultural or benefit-relevant indicators, among other strategies.[62-66] (See discussion of California's social-ecological framework and the Quadra Island Workshop report in Supplementary Report for further commentary on the value of a linked social-ecological monitoring approach).

- Integrated social-ecological monitoring can track leading indicators of MPA effectiveness (e.g., decline in human pressures that cause ecological impacts) or early warnings about potential threats, and more generally support the design of integrated management solutions across different levels of governance.

R8. Develop a plan for long-term human dimensions monitoring and research

- Insights from MPAN case studies emphasized the need for greater focus on socio-economic and socio-cultural monitoring, which often received less attention relative to ecological monitoring. Oregon was an exception, wherein social and economic experts were brought together in the planning phase to devise a Marine Reserves Human Dimensions Monitoring Plan that served to guide the human dimensions monitoring and research. There are a lot of economic, social, and cultural marine uses and values in the NSB, and understanding their responses to MPAN implementation should be explicitly considered in the monitoring design.

- NSB MPAN partners should consider hiring at least one or more experienced social scientists to establish a robust human dimensions monitoring program. The Oregon case study found that less experienced staff or having ecological scientists and resource managers leading social science surveys and overseeing fisheries economics contracts resulted in products that were less applicable and useful to decision makers.

Bull kelp forest, Quadra Island, British Columbia © Markus Thompson

R9. Explore ways to monitor and assess the diverse outcomes and objectives of MPAN collaborative governance, with attention to the importance of reconciliation

- The collaborative governance approach for the NSB MPAN is unique in the way it seeks to support the implementation of Reconciliation Framework Agreements between First Nations and the Governments of Canada and British Columbia, along with other commitments to reconciliation principles and advancing collaborative marine governance and management (stated in the NAP). The NAP also states that "collaboratively governed and managed MPAs support First Nations' ability to maintain and meet the objectives of traditional marine management and incorporate unique protection perspectives into new collaborative management regimes" (NAP, p. 13). As such, there is value in exploring ways to assess whether the implementation of the NSB MPAN is contributing to advancing these broader collaborative governance objectives or not.

- While various elements for assessing governance effectiveness of MPANs are suggested in the literature (see section on Governance in Supplementary Report for further discussion), the case studies examined do not have a comparable Indigenous collaborative MPAN governance context to draw governance monitoring insights from. The NSB MPAN is well situated to establish new precedents here.

R10. Take stock of existing data and monitoring activities and build on these where appropriate, but develop new monitoring activities to fill gaps for MPAN evaluation and management

- The NSB MPAN monitoring should consider existing marine ecological, socio-economic, and cultural monitoring and related governance frameworks. This includes explicit consideration of how to possibly integrate programs that are ongoing as well as one-time analyses that have been conducted. Given limited monitoring resources, building on existing programs is desirable wherever possible to gain efficiencies and extend existing time series that provide critical insights into long-term processes. Some examples of organizations supporting ongoing monitoring and research in this region include:

  » Marine Plan Partnership for the North Pacific Coast (MaPP) (a partnership among 17 First Nations and the Province of British Columbia)

  » Coastal Guardians (implement the monitoring, but data is owned by Nations)

  » Coastal First Nations—Great Bear Initiative Regional Monitoring System (RMS)

  » Academic Research Institutions and Affiliates (e.g., University of Victoria, University of British Columbia, Simon Fraser University, The Hakai Institute, The Bamfield Marine Sciences Center, and others)

  » Fisheries and Oceans Canada

  » Parks Canada

  » Ocean Networks Canada

- Many existing programs may not be collecting the most appropriate data or taking place over the right spatial and temporal scales to suit the specific needs of MPAN evaluation and management. In these cases, it may be possible to modify existing programs through the collection of additional data types, adding new sampling periods, or adding new sites. In other cases entirely new monitoring activities may be needed. Given the significant time, financial, and personnel resources that are needed to initiate a new monitoring activity, this measure should be reserved for filling the most critical data gaps in existing programs. For example, efforts should be made to explore how existing dive survey programs within the region can be better integrated across sub-regions to support larger scale MPAN monitoring of subtidal indicators.

R11. Align baseline monitoring with the expectations and objectives of long-term monitoring

- Measuring and evaluating change needs to be carried out against a baseline or standard. As operationalization of the MPAN will take several years, efforts to conduct baseline monitoring *before* MPAs are fully enacted in ways that will feed into long-term monitoring data sets will greatly enhance the ability of partners to make before and after comparisons, understand causal relationships, and ultimately evaluate long-term trends and outcomes across the MPAN.

- Linking baseline monitoring to long-term monitoring can be complicated in data poor situations. When little is known about a site's habitats and species, baseline monitoring often focuses on rapid field surveys and/or expert elicitation to identify the presence and characteristics of key ecological and environmental features.

- Importantly, elicitation of Indigenous knowledge through interviews, logbooks, or similar methods can play a crucial role in both defining the baseline (e.g., pre-contact, recent past, or current state of ecological systems[157]; or baseline social perceptions about MPA establishment[158]) and documenting trends in key indicators over time based on oral history and lived experience (e.g., changes in the mean size of focal fish species[159]). When carefully planned and standardized, such knowledge surveys can also become part of long-term monitoring programs.[160,161,162] In the case of interviews with Indigenous knowledge-holders, additional work is required to respectfully co-create research strategies with the stewardship authorities of their respective Nations.

- A key component of baseline monitoring should be to identify and document human dimensions, including variable levels of human pressures from fishing and other relevant human activities that might influence MPAN outcomes, prior to implementation of new management measures. Baseline monitoring for human dimensions monitoring is also required to help identify key people, communities, and sectors to track using specific indicators moving forward.

  » California's decadal review found that the degree of past fishing pressure and time since the onset of spatial protections influence the timeline, magnitude, and detectability of MPA outcomes.

  » In Oregon, it took 10 years to understand who is being affected by marine reserves and how, and this work is now facilitating the development of a collaborative process through which human dimensions monitoring data can be interpreted to affect policy decisions.

R12. Coordinate and execute monitoring activities in ways that facilitate the flow of information necessary for knowledge integration and evidence-based decision-making

- Map the path of information flow needed to support each management decision and related monitoring objectives and questions to determine what types of inputs are needed, what analyses need to be carried out to produce them, and what data types must be collected to feed into those analyses.

- Establish clear roles and responsibilities at each step along this pathway of information flow to identify the organizations, programs, and individuals that will need to collect, aggregate, and analyze data as well as report outcomes to monitoring partners, decision-makers, and the broader public.

- Where this process reveals gaps, new roles or personnel may be needed.

R13. Establish trust, discuss data sharing needs, and negotiate data sharing agreements with monitoring partners as early as possible

- Because of the complex governance context of the NSB region, there are many sensitivities related to sharing data among First Nations, between First Nations and Crown Government partners, and with the wider public. These sensitivities challenge the aggregation of data necessary to infer status, trends, and performance at a network level. However, case studies and published literature emphasized the importance of setting up clear systems for data sharing to enable effective network-scale evaluation. Carefully negotiated data sharing agreements in the NSB would support a path forward for network-level data aggregation and analysis. Even in situations where such agreements have been struck, further attention will be needed to ensure data quality and interoperability, local capacity for data processing and analysis, and clear pathways for how results can directly inform management decisions.

- Given that the negotiation of data sharing agreements can take many years, build in provisions that allow partners to begin collecting data that can be privately held before finalizing data sharing agreements.

- Implement strategies for protecting the privacy of certain data collected by and for First Nations, Guardians, and their partners. These strategies may include independent third-party data stewards and analysts, controlled-access data management systems or portals, and agreed-upon workflows for post-analysis aggregation of First Nations data at higher spatial scales during visualization and reporting to protect sensitive sites that would be revealed at finer spatial scales, all strategies that have previously been applied to monitoring in the MaPP region.[163]

R14. Invest in strengthening local capacity for data collection, management, and analysis to enhance regional monitoring activities of the MPAN

- Take stock of existing data collection capacity and, where gaps exist relative to planned monitoring needs, develop and implement strategies for strengthening this capacity through funding, recruiting, training, partnerships, securing equipment, and improving infrastructure before monitoring activities expand. For example, in places where dive capacity does not exist but is needed to enable regional-scale subtidal indicator monitoring, the possibility for new research or industry partnerships, dive-team sharing, subsidies for training new scientific divers, and adoption of alternative subtidal survey methods (e.g., using remotely operated vehicles, drop-cameras, baited underwater video stations, and/or eDNA) should be considered. Secure employment will also be required to ensure that training leads to jobs for those who are trained.

- For data types that require processing of field samples following collection, proactively training personnel and adding supporting infrastructure may also be required to prevent bottlenecks in processing capacity (e.g., dozens of settlement plates that must be analyzed by a very small number of qualified taxonomists, or hundreds of eDNA samples that must be channeled through just one or two qualified government labs).

- Support the expansion or establishment of independent sub-regional marine monitoring, analysis, and research hubs in the four sub-regions of the NSB to provide coordination as well as logistical and technical support to community-based monitoring and research programs (e.g., similar to the support Central Coast Indigenous Resource Alliance and the Hakai Institute have provided on the Central Coast). Such institutions may also fulfill the role of independent third-party data stewards to protect data privacy, as noted above.

- Develop a practical marine data management and analysis professional development program and supporting reference materials aimed at existing regional stewardship staff to strengthen capacity for distributed data processing, management, and analysis. Such a program could be similar in nature to the Great Bear Initiative-led Stewardship Technicians Training Program (STTP), but targeted at individuals other than Guardians to support a greater degree of specialization and division of labour across stewardship staff and departments.

- Plan ahead for the significant volumes of data that electronic monitoring methods will produce and build on existing regional capacity for 'big data' data management and storage (e.g., Ocean Networks Canada data management services and the Oceans 3.0 Data Portal, Canadian Integrated Ocean Observing System (CIOOS) platform).

- Ensure that capacity building includes putting First Nations people in leadership roles, not only technician roles, and enable pathways for career advancement and succession within stewardship departments.

2.2 Recommendations for Data Collection and Management

R15. Choose indicators through a transparent, collaborative, and repeatable selection process

- It is intractable to attempt to monitor all potentially-relevant indicators. Difficult decisions will need to be made about what to monitor, when, and how, through an indicator and monitoring prioritization process. When in doubt, start small and plan to scale up later.

- The indicator selection process is typically guided by a set of selection criteria, which typically include management criteria (e.g., relevant to goals and objectives, comprehensive, comprehensible, co-developed to reflect partner vales), technical criteria (e.g., sensitive, scalable, responsive, reliable, complementary, or has prior data availability), and logistical criteria (e.g., measurable, feasible, timely, low-impact, and cost-effective). Including 'suite-level' indicator selection criteria is also helpful to assess complementarity and redundancy across candidate indicators to ensure they include a balanced mix of indicators relevant to multiple dimensions, scales of organization, and response times.[164,165]

- A participatory approach for indicator selection is essential so that all partners can share and add their expertise to monitoring efforts. Importantly, Indigenous knowledge and science need to be central to the selection process. An indicator selection process that is transparent and well-documented allows it to be repeated in future years as emerging insights and changing environmental conditions may drive the need to revisit and refine the initial suite of indicators (e.g., dropping redundant or impractical indicators, adding new ones to track emerging phenomena, etc.).

- Begin the indicator selection process by first reviewing the outcomes of previous indicator selection processes for existing monitoring activities in the region (e.g., MaPP ecosystem-based monitoring indicators, First Nations ecosystem and fisheries monitoring indicators, Pacific North Coast Integrated Management Area Plan for Ecosystem-Based Management indicator selection), to understand what prioritization strategies were used and which indicators can be carried forward. Indicators carried forward may have the built-in benefit of prior baseline data. Examining prior efforts may also offer lessons about how and why they were, or were not, successfully operationalized in monitoring programs to avoid repeating past mistakes.

R16. Consider indicators that are relevant to multiple types of management questions and outcomes

- Include indicators previously shown to better detect 'MPA effects' (i.e., difference in indicator status inside and outside of MPAs), rather than simply defaulting to more commonly used indicators (e.g., monitoring population size distribution or density by stage rather than density or mean size and monitoring biodiversity using evenness rather than species richness).[166,167,168]

- Include indicators that capture 'fast' and 'slow' processes, both of which are important for MPA assessment and management. For example, MPA indicators directly tied to changes in indicators of interest are often slow-responding or lagging indicators (e.g., changes in biomass of slow-growing fish) and should be paired with fast-responding or leading indicators (e.g., changes in annual growth or recruitment rates, marine uses, compliance) to support proactive management responses.[169,170,171]

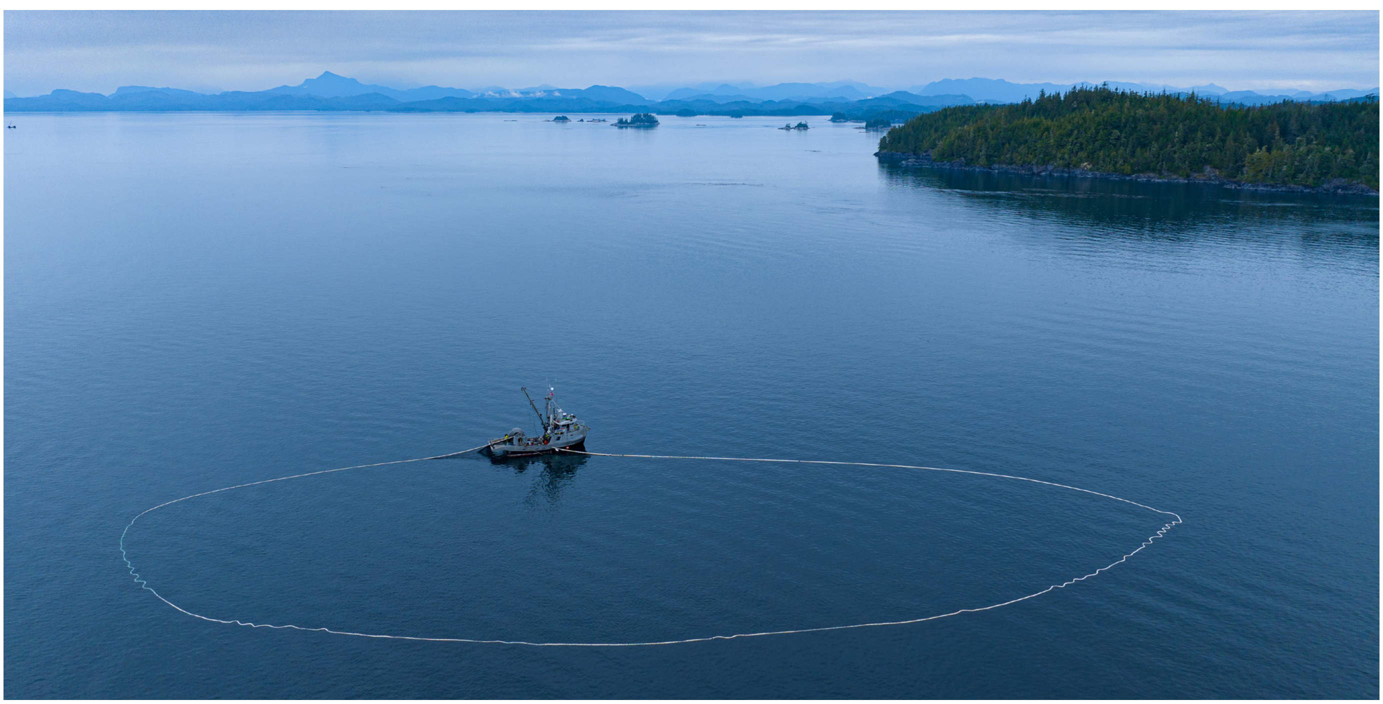
- Include indicators of network-level function and effectiveness, such as change over time in the replication or representation of key habitats in the network and the degree of ecological connectivity for key species of conservation interest.

- Include indicators that capture linkages between environmental, ecological, social, and governance domains, integrate information on responses to management actions, and help to identify the most appropriate entry points along the causal chain for targeted intervention.[64-66] For example, implementation of MPAs may influence changes in fish biomass and abundance, leading to spillover that has cascading benefits for fisheries and food security, and which can influence support for MPAs at governance tables.

R17. Apply a monitoring prioritization framework across multiple indicators and sites to scale monitoring efforts to available resources

- Given the broad geographic scale of the NSB and the number of individual MPA sites that will be encompassed by the network, it will not be practical to carry out monitoring activities at each site in each year. A tiered monitoring prioritization scheme will be needed to decide where and when monitoring occurs, which may require rotating through sites across years, or a combination of annual monitoring at some sites and less frequent monitoring at others (see section on Adapting Monitoring Designs to Practical Constraints in the Supplementary Report for more details).

- Monitoring prioritization across sites should consider factors such as *indicator priority* (e.g., identify "core" and "secondary" indicators), *site priority* (e.g., based on representation of key habitats, historical or ongoing threats, distance to communities, traditional and contemporary use, cultural significance, prior monitoring efforts, or similar considerations), and *methodological priority* (e.g., prioritizing simpler over more complex methods), and many monitoring frameworks will incorporate multiple and sometimes sequential prioritization considerations.



Test fishing, Broughton Archipelago, British Columbia © Markus Thompson

- A tiered monitoring strategy that can be scaled up or down is preferred and will allow for the flexibility of ramping down monitoring when funding is insufficient or ramping up monitoring to take advantage of periods when monitoring resources are more abundant. Examples of tiered monitoring strategies include the Coastal First Nations Regional Monitoring System and the MaPP Regional Kelp Monitoring Program as well as examples from the California and Victoria (Australia) case studies in the Supplementary Report.

R18. Develop sampling designs that will support robust inferences about MPAN outcomes while anticipating the constraints of field logistics

- Establish key monitoring objectives and questions prior to data collection so that data collection focuses on data that is directly relevant and useful.

- Develop sampling designs enabling the evaluation of causal relationships between MPA establishment and social-ecological outcomes using best practice principles of randomization, spatially balanced sampling, master sample frames, control or reference sites, and spatial or temporal considerations that may affect the interpretation of results (see section on Monitoring and Sampling Design in the Supplementary Report). Designs should seek to include existing 'legacy' monitoring sites wherever possible to build upon existing time series.

- Use a nested monitoring framework that facilitates data collection, aggregation, and analysis across multiple scales, including habitat, site, sub-regional network, and whole network scales.

  » The NSB already has a nested governance framework established to support the development and subsequent implementation of the Marine Plan Partnership Marine Plans, including sub-regional and regional monitoring activities. This framework includes individual spatial management sites and zones, which are grouped into four sub-regions associated with sub-regional marine plans, which are in turn part of the overall MaPP region and its regional governance structure. The MPAN should continue to leverage this system of nestedness that exists, putting more emphasis and effort into sampling designs, analytical strategies, and data sharing agreements that facilitate effectiveness evaluation at multiple scales of organization.

R19. Leverage emerging monitoring technologies to overcome regional capacity constraints and enable a wider range of indicators to be consistently monitored across the region

- Leverage emerging eDNA techniques to lower the barriers to monitoring of subtidal indicators. Passive eDNA collection methods can be used to collect samples from the surface without the need for specialized training or equipment, which are then sent to a lab for analysis, should also be considered as supplementary tool for rapid community-based subtidal biodiversity monitoring (see section on eDNA Metabarcoding in Supplementary Report). Although eDNA captures primarily species richness as opposed to observational methods that can also capture relative abundance or size distributions, it can be a useful alternative when observation-based subtidal monitoring options are not available (described in detail in Tools and Methods section in Supplementary Report).

- Leverage automated remote sensing technologies to monitor ecological and human indicators across the NSB. Hydrophones, motion-activated shore-based cameras, cabled community observatories, FerryBoxes, drones, and satellite remote sensing methods, paired with emerging machine learning approaches to automated data processing and 'event-detection', provide tractable approaches to gaining insights into site and network-scale ecological (e.g., extent of kelp and seagrass habitats, detection of marine megafauna) and human indicators (e.g., marine use and compliance that can inform targeted allocation of patrol, education, and enforcement efforts). Several of these methods are already being piloted or broadly implemented within the NSB.[172,173,174,175,176] See the Tools and Methods section in Supplementary Report for more specific examples. When these approaches are used for human activity monitoring, they should consider the privacy of individual marine users and work with user groups to balance level of detail, usefulness for management, and individual marine user privacy and support.

- Leverage innovative off-site participatory science to draw on additional capacity both inside and outside the NSB for processing and analyzing large volumes of data arising from electronic monitoring methods. Innovative programs have been able to crowd-source processing data such as images or videos. For example, using platforms such as SciStarter or Zooniverse, volunteer scientists have been engaged in identifying and categorizing underwater images (e.g., the Spyfish Aotearoa project in Aotearoa New Zealand helps to count fish in marine reserves).

- New methods should be piloted as early as possible to confirm their value and iron out logistical issues before they are broadly adopted, and programs should not necessarily expect to collect usable data in their first year of deployment. For new methods that are broadly adopted, develop a comprehensive training and capacity-building strategy including recurring hands-on training, reference manuals and videos, and train-the-trainer programs to ensure the sustainability of these methods over time given the potential for staff turnover (e.g., following the successful example of the training strategy adopted by MaPP for its kelp monitoring initiative).

- Adopt new technologies alongside existing ones to enable continuation of existing time series, facilitate comparisons, and potentially develop functional relationships and correction factors so that more tractable methods might serve as a proxy for more resource-intensive methods in the future. For example, the Hakai Institute has carried out diving studies to develop morphometric relationships between individual kelp stipe diameter and whole-plant biomass to enable future estimation of the total biomass of kelp beds based on surface-based monitoring alone.

R20. Select data collection tools, methods, and strategies in collaboration with local and Indigenous communities and other monitoring partners to align with past and current cultural context, knowledge, and practice

- Monitoring programs must provide for the consideration, collection, and use of informal and formal, quantitative and qualitative Indigenous knowledge and science—encompassing oral histories and thousands of years of observing and living on the land—in the establishment of baselines and evaluation of MPAN effectiveness.

- Data collection methods should be co-designed by monitoring partners, especially First Nations, beginning by first understanding how community monitoring partners already interact with marine areas, resources, and users and building data collection opportunities into existing practices (e.g., providing a place for Guardians to record qualitative as well as quantitative observations on data entry forms; revisiting prior traditional use studies, holding interviews, and visiting key locations with knowledge holders; use of logbooks or mobile apps for recording opportunistic community observations during regular marine travel or harvesting activities that could be used to ground-truth remote sensing data or eDNA data; using traditional gears to deploy monitoring equipment, etc.)[100]. This approach can help to reduce barriers to engagement in monitoring activities, uphold cultural continuity, and improve the overall efficiency of data collection programs. It also facilitates knowledge transfer and increases the likelihood that monitoring can be sustained over time despite turnover in technical staff, which is an ongoing concern in the NSB. This process should carry forward lessons learned from prior sub-regional and regional monitoring initiatives.

- Site selection and sampling design for monitoring activities should be carried out in collaboration with local and Indigenous monitoring partners to incorporate knowledge on ecological, socio-cultural, and logistical considerations (e.g., as in the MaPP kelp monitoring initiative). This knowledge can play an important role in grounding sampling designs within the place-based context of local species and habitat distributions, field conditions, and monitoring capacity.

Octopus in den, Aristazabal Island, British Columbia © Markus Thompson

2.3 Recommendations for Analyses and Reporting

R21. Decide on analytical workflows before data collection takes place and make the process transparent and repeatable

- Decide on and record the preferred approach for data aggregation and analysis before data collection begins so that data collection can be optimized to provide all required inputs for this workflow and reduce the need for costly unplanned data collection or additional analytical assumptions that reduce confidence in results.[178]

- Document expected analyses and provide templates for expected results and reporting formats as part of monitoring plans (e.g., standardized reporting metrics and plots for each analysis and monitoring question, as in Aotearoa New Zealand's Marine Monitoring and Reporting Framework) to set clear expectations and improve standardization of reporting across partners, sites, regions, and years.

- Consider the development of standardized scripts, web platforms, and other tools to automate data processing and analysis when appropriate and lower the barriers to broader participation in this stage of monitoring (e.g., the Hakai Institute's Kelp-O-Matic Tool to automate processing of drone survey imagery of kelp) and evaluation (e.g., the web-based R shiny app MAREA for automated analysis of indicator data). Automation can also significantly reduce the workload needed to produce regular monitoring reports, which is a challenge for many stewardship offices in the NSB region due to capacity constraints.

- Analytical workflows should include clear guidance for quantifying, acknowledging, and clearly communicating uncertainty arising from data gaps or assumptions required for the use of complex analytical methods. Doing so helps readers interpret findings, avoids overinterpreting results, builds credibility and confidence in decision-making, and enables the identification of research priorities to help explicitly reduce these uncertainties in the future.

R22. Choose analytical methods that are robust to the inevitable occurrences of unbalanced sampling or other irregularities in data collection

- Spatially-balanced and randomized sampling designs are the gold standard of monitoring designs for establishing the causes of patterns observed in data, which is essential for establishing the effectiveness of management interventions like MPAs. However, randomized studies are not always possible in an environmental context for a variety of reasons, including a non-random distribution of MPA sites and stressors or logistical issues such as poor weather during field work that results in missed sites or other data gaps, which are known issues in the NSB MPAN.

- Given the likelihood of imperfect data, monitoring strategies should plan ahead to apply more sophisticated statistical methods robust to unbalanced sampling. For example, statistical matching of reference or 'control' sites at the monitoring design stage can help to approximate a randomized design, while the use of generalized linear mixed effects models (GLMMs) with spatial and spatiotemporal random fields at the analysis stage can account for unbalanced data and uncontrolled confounding factors to maintain the ability to make robust inferences.[120]

R23. Consider the trade-offs between accessibility, complexity, and uncertainty when selecting analytical methods

- Whenever possible, monitoring data should first be analyzed using simpler analytical methods that are easier to implement and interpret. Simpler methods lend themselves better to automation and would help to enable regional monitoring partners to play a greater role in analysis, evaluation, and reporting. This would allow for a more distributed approach to analytical efforts that would provide built-in opportunities for cross-validation and yield more timely results for use in proactive management.

- In other cases, the use of more complex analytical methods requiring specialized technical skills may be unavoidable, particularly when using monitoring data to assess network-scale processes and causal relationships (e.g., network-scale models to measure changes in ecological connectivity or regional species distribution models to measure changes in representation). Such methods may require additional data aggregation and assumptions that may increase the degree of uncertainty in results. In these cases, the use multiple complementary modelling fitting methods in an ensemble modelling approach (e.g., habitat suitability index (HSI) models, generalized linear models (GLMs), and boosted regression tree (BRTs) approaches to species distribution modeling[179]) can help to offset the biases and shortcomings of individual methods to increase confidence in the results.

R24. Use monitoring data as inputs to state-of-the-art analytical methods to infer performance at a network scale, which would be difficult or impossible to measure directly

- Although the NSB MPAN was not designed as a connectivity network, its ecological connectivity has been assessed through connectivity models based on the expected ecological characteristics of both adult[180] and larval dispersal[181] for key species of interest. As in California[182,183], such connectivity models could draw on monitoring data to update parameters on dispersal distances and recruitment rates to assess how connectivity is changing over time following MPA establishment. Because differences in connectivity and recruitment across sites have a large influence on timelines for meeting management objectives, this information is also crucial for interpreting the outcomes of analyses to assess MPA site and network performance.

- Similarly, monitoring data on environmental conditions and adult species distributions can be used to update region wide species distribution models to track changing habitat suitability across MPANs at multiple spatial and temporal scales to evaluate potential changes in species representation and implications for management.

- These types of analyses are essential for understanding whether the MPAN's performance is 'greater than the sum of its parts'.

Red Irish lord, Gods Pocket Marine Provincial Park, British Columbia © Markus Thompson

R25. Plan for integrated analyses of social-ecological processes rather than evaluating the different domains of MPAN performance in isolation

- As this report recommends a social-ecological framework for monitoring, it follows that analytical approaches should consider the connections between social and ecological indicators and dimensions. Literature on social-ecological systems offers innovative approaches for analyzing and modelling linked social and ecological processes (see discussion of California's social-ecological framework and the Quadra Island Workshop report in Supplementary Report).

R26. Prioritize communications on monitoring progress and results, making use of multiple reporting outlets and modalities to reach different audiences

- Documentation of the monitoring process (e.g., via photos, videos, interviews) and monitoring outcomes (e.g., report cards, reports, datasets, StoryMaps) should be funded and made accessible through a central online hub (e.g., https://mpanetwork.ca/) in a variety of formats that are accessible and relevant to different audiences. Whereas peer-reviewed journal articles can help to document and ensure the rigour of monitoring and analytical methods, printable brochures, interactive websites, and social media can be geared for more general audiences. Importantly, effectively engaging First Nations audiences will also require alternative and culturally-aligned communication strategies.

- Develop an explicit communications and engagement strategy for non-technical communication to the public, First Nations communities, and stakeholders. This is particularly important for communicating on the outcomes of human dimensions research, which may contain information tied to livelihoods, cultural values, and marine activities that are of particular interest for people, and help build transparency, trust, and ownership in MPAN management and monitoring.

R27. Set realistic expectations about anticipated outcomes and response times for key indicators and objectives following MPAN establishment when communicating with partners, decision-makers, and the public

- As noted in the section on Recommendations for Early Stages of MPAN Implementation, predictions of MPA outcomes that incorporate known influencing factors on MPA performance are important for interpreting monitoring data.

- Communicating anticipated monitoring outcomes and associated time frames are critical for setting realistic expectations for responses following MPA establishment so that partners, decision-makers, and the public are not surprised or disappointed if certain changes are not detectable in the first five to ten years. It is worth considering that detectable changes in socio-economic and other human dimension indicators might occur on shorter timescales than some of the ecological species or habitat responses. As previously noted, selecting a mix of indicators that are expected to respond more quickly and more slowly will help to demonstrate some short-term changes and outcomes of the MPAN and maintain public and partner interest, engagement, and trust.

R28. Establish regular reporting intervals to ensure that managers, monitoring partners, and the broader community of marine users continue to value and support monitoring of the MPAN

- Reporting intervals may be tiered depending on the reporting product, with shorter intervals to keep partners up to date on progress and maintain support during planning and implementation (e.g., social media, news posts, webinars) and longer intervals for full-fledged reporting of monitoring outcomes or programmatic reviews (e.g., report cards, technical reports, decadal reviews). Reporting intervals for monitoring outcomes in reviewed MPAN cases generally range between six and ten years.

R29. Make monitoring data publicly accessible via online portals to increase transparency, accountability, and trust

- Before data can be made public, data management should adhere to best practices that correspond to the types of data that are collected. Data concerning and/or collected by Indigenous partners should be maintained in accordance with data sharing agreements developed in collaboration with those partners. Data collected by and/or for government agencies should be maintained in accordance with government regulations and where possible adhere to FAIR data principles. Public access to data can help to engage more audiences such as researchers that can use the data to ask new questions about the NSB or test novel methods for analysis that could one day be adopted into the broader monitoring program.

- Where possible, data should be made publicly available through existing portals, from the more generalized (e.g., Canada's Open Data Portal) to the more specialized (e.g., the Canadian Integrated Ocean Observing System (CIOOS), or through the development of a custom data portal for storing information from the NSB MPAN (e.g., MaPP's Marine Plan Portal, the UK's Marine Environmental Data and Information Network (MEDIN), or the UK Joint Nature Conservation Committee's MPA Mapper).

R30. Regularly evaluate the monitoring program and remain open to learning and adaptation

- While it is important to initiate data collection, management, and analysis to provide baseline information and contribute to long-term monitoring, it is also important to recognize opportunities for adaptive learning over time.

- Monitoring program review helps to understand where refinements are needed to streamline data collection logistics, increase efficiency, improve statistical rigor, and fill knowledge gaps. This process may involve repeating the indicator or monitoring prioritization framework applied in earlier steps, paying special attention to new information and lessons learned that have emerged since the prior application.

- Monitoring program review is a multitiered process that can apply to individual monitoring components and programs (e.g., the fish community monitoring component of the subtidal monitoring program) as well as the broader MPAN monitoring enterprise in which they are embedded, with special attention to whether data can be used to answer questions that are linked to MPAN management objectives.

- Many of the case study experts emphasized that MPAN monitoring has been an iterative learning process that has yielded important lessons through multiple pathways.

  » In California, there have been inconsistencies in ongoing data collection (e.g., due to differing levels of funding over time), a downsizing of the initial monitoring plan due to practical or financial constraints, and an appreciation for the need to tie monitoring goals to larger MPAN goals.

  » In Victoria, Australia, monitoring began in 1998 and underwent periodic incremental adjustments before monitoring program managers recognized the need for a full-program evaluation and upgrade (2015 to present) to streamline the program and improve its ability to inform evidence-based management. This review process helped to identify indicators that should be added, modified, or dropped based on early experiences and feedback from monitoring partners177 (see also Victoria (Australia) case study in Supplementary Report).

Seaweed monitoring, Vancouver Island, British Columbia © Markus Thompson

Concluding Remarks

As communities and countries around the world forge ahead towards the establishment of MPANs to meet both local conservation objectives and global commitments to conservation targets, existing and new MPANs stand to benefit from the lessons learned by early adopters that are now undergoing retrospective reviews and evaluations. Although no single MPAN has yet addressed every aspect of emerging best practice, each offers its own successes and insights to learn from. Further research continues to build on these practical insights to open up new possibilities in this space.

Through careful consideration of the lessons and recommendations outlined in this report, partners working towards monitoring and management strategies in the Northern Shelf Bioregion and other emerging MPANs have the opportunity to set new precedents for integrated, collaborative, and rigorous social-ecological monitoring, evaluation, and management of these networks moving forward.

Kelp survey, Broken Group Islands, British Columbia © Markus Thompson

References Cited

1. Laffoley, D., 2008. Establishing resilient marine protected area networks-making it happen: Full technical version, including ecological, social and governance considerations, as well as case studies. IUCN.

2. MPA Network BC Northern Shelf Initiative, 2023. Network Action Plan. Compendium 2.

3. Gill, D.A., Mascia, M.B., Ahmadia, G.N., Glew, L., Lester, S.E., Barnes, M., Craigie, I., Darling, E.S., Free, C.M., Geldmann, J. and Holst, S., 2017. Capacity shortfalls hinder the performance of marine protected areas globally. Nature, 543(7647), pp.665-669.

4. Alexander, S.M., Andrachuk, M. and Armitage, D., 2016. Navigating governance networks for community-based conservation. Frontiers in Ecology and the Environment, 14(3), pp.155-164.

5. Hall-Arber, M., Murray, S., Aylesworth, L., Carr, M., Field, J., Grorud-Colvert, K., Martone, R., Nickols, K., Saarman, E. and Wertz, S., 2021. Scientific Guidance for California's MPA Decadal Reviews: A Report by the Ocean Protection Council's Science Advisory Team Working Group and California Ocean Science Trust. Available from: https://www.opc.ca.gov/webmaster/_media_library/2022/01/Evaluating-Californias-Marine-Protected-Area-Network-2021_ADA_OST_revised12.2022.pdf

6. Marine Protected Area Monitoring Action Plan. 2018. California Department of Fish and Wildlife and California Ocean Protection Council, California, USA. October 2018.

7. Hall-Arber, M., Murray, S., Aylesworth, L., Carr, M., Field, J., Grorud-Colvert, K., Martone, R., Nickols, K., Saarman, E. and Wertz, S., 2021. Scientific Guidance for California's MPA Decadal Reviews: A Report by the Ocean Protection Council's Science Advisory Team Working Group and California Ocean Science Trust. Available from: https://www.opc.ca.gov/webmaster/_media_library/2022/01/Evaluating-Californias-Marine-Protected-Area-Network-2021_ADA_OST_revised12.2022.pdf [see Appendix 1 and 2]

8. Danovaro, R., Fanelli, E., Aguzzi, J., Billett, D., Carugati, L., Corinaldesi, C., Dell'Anno, A., Gjerde, K., Jamieson, A.J., Kark, S. and McClain, C., 2020. Ecological variables for developing a global deep-ocean monitoring and conservation strategy. Nature Ecology & Evolution, 4(2), pp.181-192.

9. Ehrman, A, Loseto, L., Pućko, M., Melling, H., Michel, C., Reist, J., McNicholl, D., and Dunmall, K. 2022. Potential ecological monitoring indicators and strategies for the Anguniaqvia niqiqyuam Marine Protected Area and a synopsis of available information. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/036. vii + 148 p.

10. Eddy, B.G., Hearn, B., Luther, J.E., van Zyll de Jong, M., Bowers, W., Parsons, R., Piercey, D., Strickland, G. and Wheeler, B., 2014. An information ecology approach to science–policy integration in adaptive management of social-ecological systems. Ecology and society, 19(3).

11. Ahmadia, G.N., Glew, L., Provost, M., Gill, D., Hidayat, N.I., Mangubhai, S., Purwanto and Fox, H.E., 2015. Integrating impact evaluation in the design and implementation of monitoring marine protected areas. Philosophical Transactions of the Royal Society B: Biological Sciences, 370(1681), p.20140275.

12. Hayes, K.R., Hosack, G.R., Lawrence, E., Hedge, P., Barrett, N.S., Przeslawski, R., Caley, M.J. and Foster, S.D., 2019. Designing monitoring programs for marine protected areas within an evidence based decision making paradigm. Frontiers in Marine Science, 6, p.746.

13. Thiault, L., Kernaléguen, L., Osenberg, C.W., Lison de Loma, T., Chancerelle, Y., Siu, G. and Claudet, J., 2019. Ecological evaluation of a marine protected area network: A progressive-change BACIPS approach. Ecosphere, 10(2), p.e02576.

14. Van Diggelen, A.D., Worden, S.E., Frimodig, A.J. and Wertz, S.P., 2022. California's lessons learned and recommendations for effective marine protected area network management. Marine Policy, 137, p.104928.

15. Reynolds, J.H., Knutson, M.G., Newman, K.B., Silverman, E.D. and Thompson, W.L., 2016. A road map for designing and implementing a biological monitoring program. Environmental Monitoring and Assessment, 188, pp.1-25.

16. Hayes, K.R., Hosack, G.R., Lawrence, E., Hedge, P., Barrett, N.S., Przeslawski, R., Caley, M.J. and Foster, S.D., 2019. Designing monitoring programs for marine protected areas within an evidence based decision making paradigm. Frontiers in Marine Science, 6, p.746.

17. Dunham, A., Dunham, J.S., Rubidge, E., Iacarella, J.C. and Metaxas, A., 2020. Contextualizing ecological performance: Rethinking monitoring in marine protected areas. Aquatic Conservation: Marine and Freshwater Ecosystems, 30(10), pp.2004-2011.

18. Longo, C., Halpern, B.S., Lindermayer, D., Barton, P. and Pierson, J., 2015. Building indicators for coupled marine socio-ecological systems. Ch 14 in: Lindenmayer, D, Barton, P, & Pierson, J (eds) 2015, Indicators and Surrogates of Biodiversity and Environmental Change, CSIRO Publishing, Collingwood.

19. Dunham, A., Dunham, J.S., Rubidge, E., Iacarella, J.C. and Metaxas, A., 2020. Contextualizing ecological performance: Rethinking monitoring in marine protected areas. Aquatic Conservation: Marine and Freshwater Ecosystems, 30(10), pp.2004-2011.

20. Meehan, M.C., Ban, N.C., Devillers, R., Singh, G.G. and Claudet, J., 2020. How far have we come? A review of MPA network performance indicators in reaching qualitative elements of Aichi Target 11. Conservation Letters, 13(6), p.e12746.

21. Tony, A.B.R. 2020. Adaptive management in context of MPAs: Challenges and opportunities for implementation. Journal for Nature Conservation, 56, p.125864.

22. Ehrman, A, Loseto, L., Pućko, M., Melling, H., Michel, C., Reist, J., McNicholl, D., and Dunmall, K. 2022. Potential ecological monitoring indicators and strategies for the Anguniaqvia niqiqyuam Marine Protected Area and a synopsis of available information. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/036. vii + 148 p.

23. Hayes, K.R., Hosack, G.R., Lawrence, E., Hedge, P., Barrett, N.S., Przeslawski, R., Caley, M.J. and Foster, S.D., 2019. Designing monitoring programs for marine protected areas within an evidence based decision making paradigm. Frontiers in Marine Science, 6, p.746.

24. Ehrman, A, Loseto, L., Pućko, M., Melling, H., Michel, C., Reist, J., McNicholl, D., and Dunmall, K. 2022. Potential ecological monitoring indicators and strategies for the Anguniaqvia niqiqyuam Marine Protected Area and a synopsis of available information. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/036. vii + 148 p.

25. Pfister, C.A., Altabet, M.A. and Weigel, B.L., 2019. Kelp beds and their local effects on seawater chemistry, productivity, and microbial communities. Ecology, 100(10), p.e02798.

26. Pelletier, D., García-Charton, J.A., Ferraris, J., David, G., Thébaud, O., Letourneur, Y., Claudet, J., Amand, M., Kulbicki, M. and Galzin, R., 2005. Designing indicators for assessing the effects of marine protected areas on coral reef ecosystems: a multidisciplinary standpoint. Aquatic Living Resources, 18(1), pp.15-33.

27. Meehan, M.C., Ban, N.C., Devillers, R., Singh, G.G. and Claudet, J., 2020. How far have we come? A review of MPA network performance indicators in reaching qualitative elements of Aichi Target 11. Conservation Letters, 13(6), p.e12746.

28. O'Leary, B.C., Copping, J.P., Mukherjee, N., Dorning, S.L., Stewart, B.D., McKinley, E., Addison, P.F., Williams, C., Carpenter, G., Righton, D. and Yates, K.L., 2021. The nature and extent of evidence on methodologies for monitoring and evaluating marine spatial management measures in the UK and similar coastal waters: a systematic map. Environmental Evidence, 10(1), pp.1-23.

29. Pelletier, D., García-Charton, J.A., Ferraris, J., David, G., Thébaud, O., Letourneur, Y., Claudet, J., Amand, M., Kulbicki, M. and Galzin, R., 2005. Designing indicators for assessing the effects of marine protected areas on coral reef ecosystems: a multidisciplinary standpoint. Aquatic Living Resources, 18(1), pp.15-33.

30. Soykan, C.U. and Lewison, R.L., 2015. Using community-level metrics to monitor the effects of marine protected areas on biodiversity. Conservation Biology, 29(3), pp.775-783.

31. Pelletier, D., García-Charton, J.A., Ferraris, J., David, G., Thébaud, O., Letourneur, Y., Claudet, J., Amand, M., Kulbicki, M. and Galzin, R., 2005. Designing indicators for assessing the effects of marine protected areas on coral reef ecosystems: a multidisciplinary standpoint. Aquatic Living Resources, 18(1), pp.15-33.

32. Jaco, E.M. and Steele, M.A., 2020. Early indicators of MPA effects are detected by stereo-video. Marine Ecology Progress Series, 647, pp.161-177.

33. Meehan, M.C., Ban, N.C., Devillers, R., Singh, G.G. and Claudet, J., 2020. How far have we come? A review of MPA network performance indicators in reaching qualitative elements of Aichi Target 11. Conservation Letters, 13(6), p.e12746.

34. Pelletier, D., García-Charton, J.A., Ferraris, J., David, G., Thébaud, O., Letourneur, Y., Claudet, J., Amand, M., Kulbicki, M. and Galzin, R., 2005. Designing indicators for assessing the effects of marine protected areas on coral reef ecosystems: a multidisciplinary standpoint. Aquatic Living Resources, 18(1), pp.15-33.

35. Soykan, C.U. and Lewison, R.L., 2015. Using community-level metrics to monitor the effects of marine protected areas on biodiversity. Conservation Biology, 29(3), pp.775-783.

36. Blowes, S.A., Chase, J.M., Di Franco, A., Frid, O., Gotelli, N.J., Guidetti, P., Knight, T.M., May, F., McGlinn, D.J., Micheli, F. and Sala, E., 2020. Mediterranean marine protected areas have higher biodiversity via increased evenness, not abundance. Journal of Applied Ecology, 57(3), pp.578-589.

37. Dalongeville, A., Boulanger, E., Marques, V., Charbonnel, E., Hartmann, V., Santoni, M.C., Deter, J., Valentini, A., Lenfant, P., Boissery, P. and Dejean, T., 2022. Benchmarking eleven biodiversity indicators based on environmental DNA surveys: More diverse functional traits and evolutionary lineages inside marine reserves. Journal of Applied Ecology, 59(11), pp.2803-2813.

38. Grorud-Colvert, K., Claudet, J., Tissot, B.N., Caselle, J.E., Carr, M.H., Day, J.C., Friedlander, A.M., Lester, S.E., De Loma, T.L., Malone, D. and Walsh, W.J., 2014. Marine protected area networks: assessing whether the whole is greater than the sum of its parts. PloS one, 9(8), p.e102298.

39. Roberts, K.E., Valkan, R.S. and Cook, C.N., 2018. Measuring progress in marine protection: A new set of metrics to evaluate the strength of marine protected area networks. Biological Conservation, 219, pp.20-27.

40. Balbar, A.C, Daigle, R.M., Heaslip, S.G., Jeffery, N.W., Proudfoot, B., Robb, C.K., Rubidge, E. and Stanley R. 2020. Approaches for Assessing and Monitoring Representation, Replication, and Connectivity in Marine Conservation Networks. DFO Can. Sci. Advis. Sec. Res. Doc. 2020/050. vii + 57 p.

41. Carr, M.H., Robinson, S.P., Wahle, C., Davis, G., Kroll, S., Murray, S., Schumacker, E.J., and Williams, M. 2017. The central importance of ecological spatial connectivity to effective marine protected areas and to meeting the challenges of climate change in the marine environment. Aquatic Conservation: Marine and Freshwater Ecosystems 27(S1): 6-29.

42. California Department of Fish and Wildlife and California Ocean Protection Council (CDFW and OPC). 2018. Marine Protected Area Monitoring Action Plan., California, USA. 302 pp.

43. Balbar, A.C, Daigle, R.M., Heaslip, S.G., Jeffery, N.W., Proudfoot, B., Robb, C.K., Rubidge, E. and Stanley R. 2020. Approaches for Assessing and Monitoring Representation, Replication, and Connectivity in Marine Conservation Networks. DFO Can. Sci. Advis. Sec. Res. Doc. 2020/050. vii + 57 p.

44. Friesen, S.K., Rubidge, E., Martone, R., Hunter, K.L., Peña, M.A. and Ban, N.C., 2021. Effects of changing ocean temperatures on ecological connectivity among marine protected areas in northern British Columbia. Ocean & Coastal Management, 211, p.105776.

45. Lopes, P.F.M., Mendes, L., Fonseca, V. and Villasante, S., 2017. Tourism as a driver of conflicts and changes in fisheries value chains in Marine Protected Areas. Journal of Environmental Management, 200, pp.123-134.

46. Barnes, M.L., Wang, P., Cinner, J.E., Graham, N.A., Guerrero, A.M., Jasny, L., Lau, J., Sutcliffe, S.R. and Zamborain-Mason, J., 2020. Social determinants of adaptive and transformative responses to climate change. Nature Climate Change, 10(9), pp.823-828.

47. Pham, T.T.T., 2020. Tourism in marine protected areas: Can it be considered as an alternative livelihood for local communities?. Marine Policy, 115, p.103891.

48. Gill, D.A., Mascia, M.B., Ahmadia, G.N., Glew, L., Lester, S.E., Barnes, M., Craigie, I., Darling, E.S., Free, C.M., Geldmann, J. and Holst, S., 2017. Capacity shortfalls hinder the performance of marine protected areas globally. Nature, 543(7647), pp.665-669.

49. Soares, M.O., Rossi, S., Gurgel, A.R., Lucas, C.C., Tavares, T.C.L., Diniz, B., Feitosa, C.V., Rabelo, E.F., Pereira, P.H.C., de Kikuchi, R.K.P. and Leão, Z.M., 2021. Impacts of a changing environment on marginal coral reefs in the Tropical Southwestern Atlantic. Ocean & Coastal Management, 210, p.105692.

50. Fox, H.K. and Swearingen, T.C., 2021. Using a difference-in-differences and synthetic control approach to investigate the socioeconomic impacts of Oregon's marine reserves. Ocean & Coastal Management, 215, p.105965.

51. Schreiber, M.A., Chuenpagdee, R. and Jentoft, S., 2022. Blue Justice and the co-production of hermeneutical resources for small-scale fisheries. Marine Policy, 137, p.104959.

52. Bonkoski, J., C. Chen, L. Richmond, K. Sayce, S. Cook, J. Enevoldsen, R. Fisher, D. Chin, J. Chang, M. Kia, and R. Grmela. 2021. Establishing a Statewide Baseline and Long-Term MPA Monitoring Program for Commercial and Commercial Passenger Fishing Vessel Fisheries in the State of California. www.mpahumanuses.com.

53. New Zealand Government Department of Conservation. 2022. New Zealand Marine Monitoring and Reporting Framework. Department of Conservation. Available from https://www.doc.govt.nz/contentassets/4f5439a4268f420b802a29562b112ce3/marine-monitoring-reporting-framework-2022.pdf

54. Edgar, G.J., Stuart-Smith, R.D., Willis, T.J., Kininmonth, S., Baker, S.C., Banks, S., Barrett, N.S., Becerro, M.A., Bernard, A.T., Berkhout, J. and Buxton, C.D., 2014. Global conservation outcomes depend on marine protected areas with five key features. Nature, 506(7487), pp.216-220.

55. Noble, M.M., Harasti, D., Pittock, J. and Doran, B., 2021. Using GIS fuzzy-set modelling to integrate social-ecological data to support overall resilience in marine protected area spatial planning: A case study. Ocean & Coastal Management, 212, p.105745.

56. Ziegler, S.L., Brooks, R.O., Hamilton, S.L., Ruttenberg, B.I., Chiu, J.A., Fields, R.T., Waltz, G.T., Shen, C., Wendt, D.E. and Starr, R.M., 2022. External fishing effort regulates positive effects of no-take marine protected areas. Biological Conservation, 269, p.109546.

57. Wilson, K.L., Tittensor, D.P., Worm, B. and Lotze, H.K., 2020. Incorporating climate change adaptation into marine protected area planning. Global Change Biology, 26(6), pp.3251-3267.

58. Pickard., D, Eyzaguirre, J., and Tamburello, N. 2019. Climate-Smart Fisheries Monitoring Framework. In: Eyzaguirre, J., Tamburello, N., Pickard, D., Stimson, H., Boyd, R., Jones, M., and Reygondeau, G. 2019. Analytical Tools and Monitoring Guidance for Monitoring Climate Change Impacts. CRFM Technical & Advisory Document, No. 2019 / 19. 138pp.

59. Olander, L.P., Johnston, R.J., Tallis, H., Kagan, J., Maguire, L.A., Polasky, S., Urban, D., Boyd, J., Wainger, L. and Palmer, M., 2018. Benefit relevant indicators: Ecosystem services measures that link ecological and social outcomes. Ecological Indicators, 85, pp.1262-1272.

60. Ibid.

61. Marcos, C., Díaz, D., Fietz, K., Forcada, A., Ford, A., García-Charton, J.A., Goñi, R., Lenfant, P., Mallol, S., Mouillot, D. and Pérez-Marcos, M., 2021. Reviewing the ecosystem services, societal goods, and benefits of marine protected areas. Frontiers in Marine Science, 8, p.613819.

62. Comberti, C., Thornton, T.F., De Echeverria, V.W. and Patterson, T., 2015. Ecosystem services or services to ecosystems? Valuing cultivation and reciprocal relationships between humans and ecosystems. Global Environmental Change, 34, pp.247-262.

63. Bliege Bird, R. and Nimmo, D., 2018. Restore the lost ecological functions of people. Nature Ecology & Evolution, 2(7), pp.1050-1052.

64. DeRoy, B. and Darimont, C., 2019. Biocultural indicators to support locally led environmental management and monitoring. Ecology and Society, 24(4).

65. Comberti, C., Thornton, T.F., De Echeverria, V.W. and Patterson, T., 2015. Ecosystem services or services to ecosystems? Valuing cultivation and reciprocal relationships between humans and ecosystems. Global Environmental Change, 34, pp.247-262.

66. Olander, L.P., Johnston, R.J., Tallis, H., Kagan, J., Maguire, L.A., Polasky, S., Urban, D., Boyd, J., Wainger, L. and Palmer, M., 2018. Benefit relevant indicators: Ecosystem services measures that link ecological and social outcomes. Ecological Indicators, 85, pp.1262-1272.

67. Hayes, K.R., Dambacher, J.M., Hosack, G.R., Bax, N.J., Dunstan, P.K., Fulton, E.A., Thompson, P.A., Hartog, J.R., Hobday, A.J., Bradford, R. and Foster, S.D., 2015. Identifying indicators and essential variables for marine ecosystems. Ecological Indicators, 57, pp.409-419.

68. Pendred, S., Fischer, A. and Fischer, S., 2016. Improved management effectiveness of a marine protected area through prioritizing performance indicators. Coastal management, 44(2), pp.93-115.

69. Ho, E., 2018. Criteria-based ranking (CBR): A comprehensive process for selecting and prioritizing monitoring indicators. MethodsX, 5, pp.1324-1329.

70. Hummel, H., Kalle, V., Bienfait, L., Boyer, Y., Heurich, M., Svajda, J., Adamescu, M., Cazacu, C., Medina, F.M., Morkūnė, R. and Razinkovas-Baziukas, A., 2022. A bottom-up practitioner-derived set of Essential Variables for Protected Area management. Environmental and Sustainability Indicators, 14, p.100179.

71. Cardoso-Andrade, M., Queiroga, H., Rangel, M., Sousa, I., Belackova, A., Bentes, L., Oliveira, F., Monteiro, P., Sales Henriques, N., Afonso, C.M. and Silva, A.F., 2022. Setting performance indicators for coastal marine protected areas: An expert-based methodology. Frontiers in Marine Science, 9, p.848039.

72. Gilani, H.R., Innes, J.L. and Kent, H., 2018. Developing human well-being domains, metrics and indicators in an ecosystem-based management context in Haida Gwaii, British Columbia, Canada. Society & Natural Resources, 31(12), pp.1321-1337.

73. Loring, P.A. and Hinzman, M.S., 2018. "They're All Really Important, But…": Unpacking How People Prioritize Values for the Marine Environment in Haida Gwaii, British Columbia. Ecological Economics, 152, pp.367-377.

74. Rice, J.C. and Rochet, M.J., 2005. A framework for selecting a suite of indicators for fisheries management. ICES Journal of Marine Science, 62(3), pp.516-527.

75. Olander, L.P., Johnston, R.J., Tallis, H., Kagan, J., Maguire, L.A., Polasky, S., Urban, D., Boyd, J., Wainger, L. and Palmer, M., 2018. Benefit relevant indicators: Ecosystem services measures that link ecological and social outcomes. Ecological Indicators, 85, pp.1262-1272.

76. Loh, T.L., Archer, S.K. and Dunham, A., 2019. Monitoring program design for data-limited marine biogenic habitats: A structured approach. Ecology and Evolution, 9(12), pp.7346-7359.

77. Smit, K.P., Bernard, A.T., Lombard, A.T. and Sink, K.J., 2021. Assessing marine ecosystem condition: A review to support indicator choice and framework development. Ecological Indicators, 121, p.107148.

78. Kershner, J., Samhouri, J.F., James, C.A. and Levin, P.S., 2011. Selecting indicator portfolios for marine species and food webs: a Puget Sound case study. PLoS One, 6(10), p.e25248.

79. Longo, C., Halpern, B.S., Lindermayer, D., Barton, P. and Pierson, J., 2015. Building indicators for coupled marine socio-ecological systems. Ch 14 in: Lindenmayer, D, Barton, P, & Pierson, J (eds) 2015, Indicators and Surrogates of Biodiversity and Environmental Change, CSIRO Publishing, Collingwood.

80. Breslow, S.J., Allen, M., Holstein, D., Sojka, B., Barnea, R., Basurto, X., Carothers, C., Charnley, S., Coulthard, S., Dolšak, N. and Donatuto, J., 2017. Evaluating indicators of human well-being for ecosystem-based management. Ecosystem Health and Sustainability, 3(12), pp.1-18.

81. Meehan, M.C., Ban, N.C., Devillers, R., Singh, G.G. and Claudet, J., 2020. How far have we come? A review of MPA network performance indicators in reaching qualitative elements of Aichi Target 11. Conservation Letters, 13(6), p.e12746.

82. Ocean Protection Council. 2014. The California Collaborative Approach: Marine Protected Areas Partnership Plan. Available from https://www.opc.ca.gov/webmaster/ftp/pdf/docs/mpa/APPROVED_FINAL_MPA_Partnership_Plan_12022014.pdf

83. Resource Legacy Fund. 2020. Lessons Learned from California's Marine Protected Area Network Monitoring Program. Report prepared for Nature United.

84. Ocean Protection Council. 2014. The California Collaborative Approach: Marine Protected Areas Partnership Plan. Available from https://www.opc.ca.gov/webmaster/ftp/pdf/docs/mpa/APPROVED_FINAL_MPA_Partnership_Plan_12022014.pdf

85. Maxwell, S.M., Ban, N.C. and Morgan, L.E., 2014. Pragmatic approaches for effective management of pelagic marine protected areas. Endangered Species Research, 26(1), pp.59-74.

86. Danovaro, R., Carugati, L., Berzano, M., Cahill, A.E., Carvalho, S., Chenuil, A., Corinaldesi, C., Cristina, S., David, R., Dell'Anno, A. and Dzhembekova, N., 2016. Implementing and innovating marine monitoring approaches for assessing marine environmental status. Frontiers in Marine Science, 3, p.213.

87. Mack, L., Attila, J., Aylagas, E., Beermann, A., Borja, A., Hering, D., Kahlert, M., Leese, F., Lenz, R., Lehtiniemi, M. and Liess, A., 2020. A synthesis of marine monitoring methods with the potential to enhance the status assessment of the Baltic Sea. Frontiers in Marine Science, p.823.

88. Iacarella, J.C., Burke, L., Clyde, G., Wicks, A., Clavelle, T., Dunham, A., Rubidge, E. and Woods, P., 2023a. Monitoring temporal and spatial trends of illegal and legal fishing in marine conservation areas across Canada's three oceans. Conservation Science and Practice, p.e12919.

89. Iacarella, J.C., Burke, L., Clyde, G., Wicks, A., Clavelle, T., Dunham, A., Rubidge, E. and Woods, P., 2023b. Application of AIS-and flyover-based methods to monitor illegal and legal fishing in Canada's Pacific marine conservation areas. Conservation Science and Practice, p.e12926.

90. Meehan, M.C., Ban, N.C., Devillers, R., Singh, G.G. and Claudet, J., 2020. How far have we come? A review of MPA network performance indicators in reaching qualitative elements of Aichi Target 11. Conservation Letters, 13(6), p.e12746.

91. Barnes, M.L., Wang, P., Cinner, J.E., Graham, N.A., Guerrero, A.M., Jasny, L., Lau, J., Sutcliffe, S.R. and Zamborain-Mason, J., 2020. Social determinants of adaptive and transformative responses to climate change. Nature Climate Change, 10(9), pp.823-828.

92. Pittman, S.J., Yates, K.L., Bouchet, P.J., Alvarez-Berastegui, D., Andréfouët, S., Bell, S.S., Berkström, C., Boström, C., Brown, C.J., Connolly, R.M. and Devillers, R., 2021. Seascape ecology: identifying research priorities for an emerging ocean sustainability science. Marine Ecology Progress Series, 663, pp.1-29.

93. Swanborn, D.J., Huvenne, V.A., Pittman, S.J. and Woodall, L.C., 2022. Bringing seascape ecology to the deep seabed: A review and framework for its application. Limnology and Oceanography, 67(1), pp.66-88.

94. Beger, M., Metaxas, A., Balbar, A.C., McGowan, J.A., Daigle, R., Kuempel, C.D., Treml, E.A. and Possingham, H.P., 2022. Demystifying ecological connectivity for actionable spatial conservation planning. Trends in Ecology & Evolution.

95. Gold, Z., Sprague, J., Kushner, D.J., Zerecero Marin, E. and Barber, P.H., 2021. eDNA metabarcoding as a biomonitoring tool for marine protected areas. PLoS One, 16(2), p.e0238557.

96. Bessey, C., Neil Jarman, S., Simpson, T., Miller, H., Stewart, T., Kenneth Keesing, J. and Berry, O., 2021. Passive eDNA collection enhances aquatic biodiversity analysis. Communications biology, 4(1), p.236

97. Jeffery, N.W., Lehnert, S., Kess, T., Layton, K., Wringe, B.F. and Stanley, R.R., 2022. Application of omics tools in designing and monitoring marine protected areas for a sustainable blue economy. Frontiers in Genetics, p.1413.

98. Lang-Wong A., Robinson C., Warner A., Glover R. & Drews C. 2023. Monitoring biodiversity returns of kelp restoration using environmental DNA (e-DNA). Report of phase 1. Ocean Wise, Vancouver. 17 pp.

99. Kachelriess, D., Wegmann, M., Gollock, M. and Pettorelli, N., 2014. The application of remote sensing for marine protected area management. Ecological Indicators, 36, pp.169-177.

100. Thompson, K.L., Reece, N., Robinson, N., Fisher, H.J., Ban, N.C. and Picard, C.R., 2019. "We monitor by living here": community-driven actualization of a social-ecological monitoring program based in the knowledge of Indigenous harvesters. Facets, 4(1), pp.293-314.

101. Thompson, K.L., Hill, C., Ojeda, J., Ban, N.C. and Picard, C.R., 2020a. Indigenous food harvesting as social–ecological monitoring: A case study with the Gitga'at First Nation. People and Nature, 2(4), pp.1085-1099.

102. Thompson, K.L., Lantz, T. and Ban, N., 2020b. A review of Indigenous knowledge and participation in environmental monitoring. Ecology and Society, 25(2).

103. Jessen, T.D., Ban, N.C., Claxton, N.X. and Darimont, C.T., 2022. Contributions of Indigenous Knowledge to ecological and evolutionary understanding. Frontiers in Ecology and the Environment, 20(2), pp.93-101.

104. Pelletier, D., 2020. Assessing the effectiveness of coastal marine protected area management: Four learned lessons for science uptake and upscaling. Frontiers in Marine Science, 7, p.545930.

105. Przeslawski R, Foster S [Eds.]. 2020. Field Manuals for Marine Sampling to Monitor Australian Waters, Version 2. Report to the National Environmental Science Program, Marine Biodiversity Hub. Geoscience Australia and CSIRO. 327 pp.

106. New Zealand Government Department of Conservation. 2022. New Zealand Marine Monitoring and Reporting Framework. Department of Conservation. Available from https://www.doc.govt.nz/contentassets/4f5439a4268f420b802a29562b112ce3/marine-monitoring-reporting-framework-2022.pdf

107. Shea, M.M., Kuppermann, J., Rogers, M.P., Smith, D.S., Edwards, P. and Boehm, A.B., 2023. Systematic review of marine environmental DNA metabarcoding studies: toward best practices for data usability and accessibility. PeerJ, 11, p.e14993.

108. Pelletier, D., Roos, D., Bouchoucha, M., Schohn, T., Roman, W., Gonson, C., Bockel, T., Carpentier, L., Preuss, B., Powell, A. and Garcia, J., 2021. A Standardized Workflow Based on the STAVIRO Unbaited Underwater Video System for Monitoring Fish and Habitat Essential Biodiversity Variables in Coastal Areas. Frontiers in Marine Science, 8, p.689280.

109. Buck, J.J., Bainbridge, S.J., Burger, E.F., Kraberg, A.C., Casari, M., Casey, K.S., Darroch, L., Rio, J.D., Metfies, K., Delory, E. and Fischer, P.F., 2019. Ocean data product integration through innovation-the next level of data interoperability. Frontiers in Marine Science, 6, p.32.

110. Neang, A.B., Sutherland, W., Beach, M.W. and Lee, C.P., 2021. Data integration as coordination: the articulation of data work in an ocean science collaboration. Proceedings of the ACM on Human-Computer Interaction, 4(CSCW3), pp.1-25.

111. Thomer, A.K., Akmon, D., York, J.J., Tyler, A.R., Polasek, F., Lafia, S., Hemphill, L. and Yakel, E., 2022. The Craft and Coordination of Data Curation: Complicating Workflow Views of Data Science. Proceedings of the ACM on Human-Computer Interaction, 6(CSCW2), pp.1-29.

112. Parlee, B., Huntington, H., Berkes, F., Lantz, T., Andrew, L., Tsannie, J., Reece, C., Porter, C., Nicholson, V., Peter, S. and Simmons, D., 2021. One-size does not fit all—a networked approach to community-based monitoring in large river basins. Sustainability, 13(13), p.7400.

113. Frid, A., McGreer, M., Wilson, K.L., Du Preez, C., Blaine, T. and Norgard, T., 2021. Hotspots for rockfishes, structural corals, and large-bodied sponges along the central coast of Pacific Canada. Scientific Reports, 11(1), p.21944.

114. Anderson, S.C., Ward, E.J., English, P.A. and Barnett, L.A., 2022. sdmTMB: an R package for fast, flexible, and user-friendly generalized linear mixed effects models with spatial and spatiotemporal random fields. bioRxiv, pp.2022-03.

115. Thompson, P.L., Anderson, S.C., Nephin, J., Haggarty, D.R., Peña, M.A., English, P.A., Gale, K.S. and Rubidge, E., 2022b. Disentangling the impacts of environmental change and commercial fishing on demersal fish biodiversity in a northeast Pacific ecosystem. Marine Ecology Progress Series, 689, pp.137-154.

116. Howe, S., Sams, M., Pocklington, J. and Rodrigue, M. 2022. DRAFT Parks Victoria's marine monitoring, evaluation and reporting program. Celebrating the 20th anniversary of the Marine National Parks and Sanctuaries. Parks Victoria Technical Series No. 118. Parks Victoria, Melbourne.

117. Caselle, J.E., Nickols, K.J., Smith, J.G., Lopazanski, C., Brun, J., Free, C., Anderson, C., Carr, M., Claudet, J., Dugan, J., Eurich, J., Francis, T., Gill, D., Hamilton, S., Kaschner, K., Mouillot, D., Raimondi, P., Starr, R. and Ziegler, S. A Synthesis of ecological and social outcomes from the California Marine Protected Area (MPA) network. NCEAS Working Group Final Report to the CA Ocean Protection Council and the CA Department of Fish and Wildlife. December 2022.

118. Pelletier, D., Claudet, J., Ferraris, J., Benedetti-Cecchi, L. and Garcìa-Charton, J.A., 2008. Models and indicators for assessing conservation and fisheries-related effects of marine protected areas. Canadian journal of fisheries and aquatic sciences, 65(4), pp.765-779.

119. Addison, P.F.E., Collins, D.J., Trebilco, R., Howe, S., Bax, N., Hedge, P., Jones, G., Miloslavich, P., Roelfsema, C., Sams, M. and Stuart-Smith, R.D., 2018. A new wave of marine evidence-based management: emerging challenges and solutions to transform monitoring, evaluating, and reporting. ICES Journal of Marine Science, 75(3), pp.941-952.

120. Frid, A., McGreer, M., Wilson, K.L., Du Preez, C., Blaine, T. and Norgard, T., 2021. Hotspots for rockfishes, structural corals, and large-bodied sponges along the central coast of Pacific Canada. Scientific Reports, 11(1), p.21944.

121. White, J.W., Botsford, L.W., Baskett, M.L., Barnett, L.A., Barr, R.J. and Hastings, A., 2011. Linking models with monitoring data for assessing performance of no-take marine reserves. Frontiers in Ecology and the Environment, 9(7), pp.390-399.

122. Addison, P.F.E., Collins, D.J., Trebilco, R., Howe, S., Bax, N., Hedge, P., Jones, G., Miloslavich, P., Roelfsema, C., Sams, M. and Stuart-Smith, R.D., 2018. A new wave of marine evidence-based management: emerging challenges and solutions to transform monitoring, evaluating, and reporting. ICES Journal of Marine Science, 75(3), pp.941-952.

123. Pelletier, D., 2020. Assessing the effectiveness of coastal marine protected area management: Four learned lessons for science uptake and upscaling. Frontiers in Marine Science, 7, p.545930.

124. Nickols, K.J., White, J.W., Malone, D., Carr, M.H., Starr, R.M., Baskett, M.L., Hastings, A. and Botsford, L.W., 2019. Setting ecological expectations for adaptive management of marine protected areas. Journal of Applied Ecology, 56(10), pp.2376-2385.

125. Hall-Arber, M., Murray, S., Aylesworth, L., Carr, M., Field, J., Grorud-Colvert, K., Martone, R., Nickols, K., Saarman, E. and Wertz, S., 2021. Scientific Guidance for California's MPA Decadal Reviews: A Report by the Ocean Protection Council's Science Advisory Team Working Group and California Ocean Science Trust. Available from: https://www.opc.ca.gov/webmaster/_media_library/2022/01/Evaluating-Californias-Marine-Protected-Area-Network-2021_ADA_OST_revised12.2022.pdf

126. Caselle, J.E., Nickols, K.J., Smith, J.G., Lopazanski, C., Brun, J., Free, C., Anderson, C., Carr, M., Claudet, J., Dugan, J., Eurich, J., Francis, T., Gill, D., Hamilton, S., Kaschner, K., Mouillot, D., Raimondi, P., Starr, R. and Ziegler, S. A Synthesis of ecological and social outcomes from the California Marine Protected Area (MPA) network. NCEAS Working Group Final Report to the CA Ocean Protection Council and the CA Department of Fish and Wildlife. December 2022.

127. Hall-Arber, M., Murray, S., Aylesworth, L., Carr, M., Field, J., Grorud-Colvert, K., Martone, R., Nickols, K., Saarman, E. and Wertz, S., 2021. Scientific Guidance for California's MPA Decadal Reviews: A Report by the Ocean Protection Council's Science Advisory Team Working Group and California Ocean Science Trust. Available from: https://www.opc.ca.gov/webmaster/_media_library/2022/01/Evaluating-Californias-Marine-Protected-Area-Network-2021_ADA_OST_revised12.2022.pdf

128. Caselle, J.E., Nickols, K.J., Smith, J.G., Lopazanski, C., Brun, J., Free, C., Anderson, C., Carr, M., Claudet, J., Dugan, J., Eurich, J., Francis, T., Gill, D., Hamilton, S., Kaschner, K., Mouillot, D., Raimondi, P., Starr, R. and Ziegler, S. A Synthesis of ecological and social outcomes from the California Marine Protected Area (MPA) network. NCEAS Working Group Final Report to the CA Ocean Protection Council and the CA Department of Fish and Wildlife. December 2022.

129. Tony, A.B.R. 2020. Adaptive management in context of MPAs: Challenges and opportunities for implementation. Journal for Nature Conservation, 56, p.125864.

130. Nickols, K.J., White, J.W., Malone, D., Carr, M.H., Starr, R.M., Baskett, M.L., Hastings, A. and Botsford, L.W., 2019. Setting ecological expectations for adaptive management of marine protected areas. Journal of Applied Ecology, 56(10), pp.2376-2385.

131. Tony, A.B.R. 2020. Adaptive management in context of MPAs: Challenges and opportunities for implementation. Journal for Nature Conservation, 56, p.125864.

132. Ibid.

133. Nickols, K.J., White, J.W., Malone, D., Carr, M.H., Starr, R.M., Baskett, M.L., Hastings, A. and Botsford, L.W., 2019. Setting ecological expectations for adaptive management of marine protected areas. Journal of Applied Ecology, 56(10), pp.2376-2385.

134. Ibid.

135. Tony, A.B.R. 2020. Adaptive management in context of MPAs: Challenges and opportunities for implementation. Journal for Nature Conservation, 56, p.125864.

136. Ibid.

137. Nickols, K.J., White, J.W., Malone, D., Carr, M.H., Starr, R.M., Baskett, M.L., Hastings, A. and Botsford, L.W., 2019. Setting ecological expectations for adaptive management of marine protected areas. Journal of Applied Ecology, 56(10), pp.2376-2385.

138. MPA Network BC Northern Shelf Initiative, 2023. Network Action Plan.

139. Ibid.

140. MPA Network BC Northern Shelf Initiative, 2023. Network Action Plan. Compendium 1.

141. MPA Network BC Northern Shelf Initiative, 2023. Network Action Plan. Compendium 2.

142. MPA Network BC Northern Shelf Initiative, 2023. Network Action Plan. Compendium 3.

143. Gill, D.A., Mascia, M.B., Ahmadia, G.N., Glew, L., Lester, S.E., Barnes, M., Craigie, I., Darling, E.S., Free, C.M., Geldmann, J. and Holst, S., 2017. Capacity shortfalls hinder the performance of marine protected areas globally. Nature, 543(7647), pp.665-669.

144. Thompson, K.L., Reece, N., Robinson, N., Fisher, H.J., Ban, N.C. and Picard, C.R., 2019. "We monitor by living here": community-driven actualization of a social-ecological monitoring program based in the knowledge of Indigenous harvesters. Facets, 4(1), pp.293-314.

145. Thompson, K.L., Hill, C., Ojeda, J., Ban, N.C. and Picard, C.R., 2020a. Indigenous food harvesting as social–ecological monitoring: A case study with the Gitga'at First Nation. People and Nature, 2(4), pp.1085-1099.

146. Reid, A.J., Eckert, L.E., Lane, J.F., Young, N., Hinch, S.G., Darimont, C.T., Cooke, S.J., Ban, N.C. and Marshall, A., 2021. "Two-Eyed Seeing": An Indigenous framework to transform fisheries research and management. Fish and Fisheries, 22(2), pp.243-261.

147. Keats, B., Wong, P., Evans, P., and Michel, L.. 2021. Mobilizing Indigenous Knowledge in Resource Management Settings: a Practical Guide. Trailmark Systems Inc. Available from: https://cbmtoolkit.trailmarksys.com/

148. Fairweather, P. 2012a. Assessing the outcomes of Victoria's existing marine protected areas for biodiversity and ecological processes—a critical review of contemporary relevant scientific approaches and literature. Part 1: Attributes and indicators for assessing the ecological outcomes from Victoria's marine protected areas. Report for the Victorian Environmental Assessment Council.

149. Fairweather, P. 2012b. Assessing the outcomes of Victoria's existing marine protected areas for biodiversity and ecological processes—a critical review of contemporary relevant scientific approaches and literature. Part 2: Review of existing scientific assessments of ecological outcomes from marine protected areas. Report for the Victorian Environmental Assessment Council.

150. Howe, S., Sams, M., Pocklington, J. and Rodrigue, M. 2022. DRAFT Parks Victoria's marine monitoring, evaluation and reporting program. Celebrating the 20th anniversary of the Marine National Parks and Sanctuaries. Parks Victoria Technical Series No. 118. Parks Victoria, Melbourne.

151. DFO (Fisheries and Oceans Canada). 2018. Developing regional benchmarks for fisheries productivity for nearshore marine habitats. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/025.

152. Costa, M., Le Baron, N., Tenhunen, K., Nephin, J., Willis, P., Mortimor, J.P., Dudas, S. and Rubidge, E., 2020. Historical distribution of kelp forests on the coast of British Columbia: 1858–1956. Applied geography, 120, p.102230.

153. Eckert, L.E., Ban, N.C., Frid, A. and McGreer, M., 2018. Diving back in time: extending historical baselines for yelloweye rockfish with Indigenous knowledge. Aquatic Conservation: Marine and Freshwater Ecosystems, 28(1), pp.158-166.

154. Nickols, K.J., White, J.W., Malone, D., Carr, M.H., Starr, R.M., Baskett, M.L., Hastings, A. and Botsford, L.W., 2019. Setting ecological expectations for adaptive management of marine protected areas. Journal of Applied Ecology, 56(10), pp.2376-2385.

155. Tony, A.B.R. 2020. Adaptive management in context of MPAs: Challenges and opportunities for implementation. Journal for Nature Conservation, 56, p.125864.

156. Nickols, K.J., White, J.W., Malone, D., Carr, M.H., Starr, R.M., Baskett, M.L., Hastings, A. and Botsford, L.W., 2019. Setting ecological expectations for adaptive management of marine protected areas. Journal of Applied Ecology, 56(10), pp.2376-2385.

157. Jardine, T.D., 2019. Indigenous knowledge as a remedy for shifting baseline syndrome. Frontiers in Ecology and the Environment, 17(1), pp.13-14.

158. Comet, S.M.T., 2017. Informing Oregon's Marine Protected Area (MPA) Baseline Past and Present Tribal Uses of Marine Resources. Master's Thesis. Portland State University. 172 pp. Available from https://seagrant.oregonstate.edu/sites/seagrant.oregonstate.edu/files/sgpubs/onlinepubs/y-17-010_informing_oregons_marine_protected_area_baseline_past_and_present_tribal_use_of_marine_resources.pdf

159. Eckert, L.E., Ban, N.C., Frid, A. and McGreer, M., 2018. Diving back in time: extending historical baselines for yelloweye rockfish with Indigenous knowledge. Aquatic Conservation: Marine and Freshwater Ecosystems, 28(1), pp.158-166.

160. Alexander, S.M., Provencher, J.F., Henri, D.A., Taylor, J.J., Lloren, J.I., Nanayakkara, L., Johnson, J.T. and Cooke, S.J., 2019. Bridging Indigenous and science-based knowledge in coastal and marine research, monitoring, and management in Canada. Environmental Evidence, 8(1), pp.1-24.

161. Thompson, K.L., Reece, N., Robinson, N., Fisher, H.J., Ban, N.C. and Picard, C.R., 2019. "We monitor by living here": community-driven actualization of a social-ecological monitoring program based in the knowledge of Indigenous harvesters. Facets, 4(1), pp.293-314.

162. Thompson, P.L., Nephin, J., Davies, S.C., Park, A.E., Lyons, D.A., Rooper, C.N., Pena, M.A., Christian, J.R., Hunter, K.L., Rubidge, E. and Holdsworth, A.M., 2022a. Groundfish biodiversity change in northeast Pacific waters under projected warming and deoxygenation. bioRxiv, pp.2022-05. Preprint.

163. Frid, A., McGreer, M., Wilson, K.L., Du Preez, C., Blaine, T. and Norgard, T., 2021. Hotspots for rockfishes, structural corals, and large-bodied sponges along the central coast of Pacific Canada. Scientific Reports, 11(1), p.21944.

164. Kershner, J., Samhouri, J.F., James, C.A. and Levin, P.S., 2011. Selecting indicator portfolios for marine species and food webs: a Puget Sound case study. PLoS One, 6(10), p.e25248.

165. Breslow, S.J., Allen, M., Holstein, D., Sojka, B., Barnea, R., Basurto, X., Carothers, C., Charnley, S., Coulthard, S., Dolšak, N. and Donatuto, J., 2017. Evaluating indicators of human well-being for ecosystem-based management. Ecosystem Health and Sustainability, 3(12), pp.1-18.

166. Pelletier, D., García-Charton, J.A., Ferraris, J., David, G., Thébaud, O., Letourneur, Y., Claudet, J., Amand, M., Kulbicki, M. and Galzin, R., 2005. Designing indicators for assessing the effects of marine protected areas on coral reef ecosystems: a multidisciplinary standpoint. Aquatic Living Resources, 18(1), pp.15-33.

167. Meehan, M.C., Ban, N.C., Devillers, R., Singh, G.G. and Claudet, J., 2020. How far have we come? A review of MPA network performance indicators in reaching qualitative elements of Aichi Target 11. Conservation Letters, 13(6), p.e12746.

168. O'Leary, B.C., Copping, J.P., Mukherjee, N., Dorning, S.L., Stewart, B.D., McKinley, E., Addison, P.F., Williams, C., Carpenter, G., Righton, D. and Yates, K.L., 2021. The nature and extent of evidence on methodologies for monitoring and evaluating marine spatial management measures in the UK and similar coastal waters: a systematic map. Environmental Evidence, 10(1), pp.1-23.

169. Walker, B.H., Carpenter, S.R., Rockstrom, J., Crépin, A.S. and Peterson, G.D., 2012. Drivers," slow" variables," fast" variables, shocks, and resilience. Ecology and Society, 17(3).

170. Kaur, S., 2020. Understanding fast and slow variables as a means to effectively manage implications of rapid change in Karimunjawa National Park, Indonesia. Master's Thesis, University of Waterloo. 192 pp.

171. Jaco, E.M. and Steele, M.A., 2020. Early indicators of MPA effects are detected by stereo-video. Marine Ecology Progress Series, 647, pp.161-177.

172. Allen, A.S., Yurk, H., Vagle, S., Pilkington, J. and Canessa, R., 2018. The underwater acoustic environment at SGaan Kinghlas-Bowie Seamount Marine Protected Area: Characterizing vessel traffic and associated noise using satellite AIS and acoustic datasets. Marine pollution bulletin, 128, pp.82-88.

173. Nijland, W., Reshitnyk, L. and Rubidge, E., 2019. Satellite remote sensing of canopy-forming kelp on a complex coastline: A novel procedure using the Landsat image archive. Remote Sensing of Environment, 220, pp.41-50.

174. Frouin-Mouy, H., Mouy, X., Pilkington, J., Küsel, E., Nichol, L., Doniol-Valcroze, T. and Lee, L., 2022. Acoustic and visual cetacean surveys reveal year-round spatial and temporal distributions for multiple species in northern British Columbia, Canada. Scientific Reports, 12(1), p.19272.

175. Gendall, L, Nelson, J.C., Martone, R., Slapcoff , L., Uduman, A., Grant, P., and McPhie, R. 2022. Megafauna from space: Using very high resolution (VHR) satellite imagery to detect whales and sharks. Can. Manuscr. Rep. Fish. Aquat. Sci. 3248: x + 50 p.

176. Gendall, L., Schroeder, S.B., Wills, P., Hessing-Lewis, M. and Costa, M., 2023. A Multi-Satellite Mapping Framework for Floating Kelp Forests. Remote Sensing, 15(5), p.1276.

177. Howe, S., Sams, M., Pocklington, J. and Rodrigue, M. 2022. DRAFT Parks Victoria's marine monitoring, evaluation and reporting program. Celebrating the 20th anniversary of the Marine National Parks and Sanctuaries. Parks Victoria Technical Series No. 118. Parks Victoria, Melbourne.

178. Maas-Hebner, K.G., Harte, M.J., Molina, N., Hughes, R.M., Schreck, C. and Yeakley, J.A., 2015. Combining and aggregating environmental data for status and trend assessments: challenges and approaches. Environmental Monitoring and Assessment, 187, pp.1-16.

179. DFO (Fisheries and Oceans Canada). 2020b.Development of a Species Distribution Modelling Framework and its Application to Twelve Species on Canada's Pacific Coast. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2020/004. (Errata: October 2020)

180. Friesen, S.K., Rubidge, E., Martone, R., Hunter, K.L., Peña, M.A. and Ban, N.C., 2021. Effects of changing ocean temperatures on ecological connectivity among marine protected areas in northern British Columbia. Ocean & Coastal Management, 211, p.105776.

181. Cristiani, J., Rubidge, E.M., Thompson, P.L., Robb, C., Hessing-Lewis, M. and O'Connor, M.I., 2023. Quantifying marine larval dispersal to assess MPA network connectivity and inform future national and transboundary planning efforts. bioRxiv, pp.2023-05.

182. Carr, M.H., Robinson, S.P., Wahle, C., Davis, G., Kroll, S., Murray, S., Schumacker, E.J., and Williams, M. 2017. The central importance of ecological spatial connectivity to effective marine protected areas and to meeting the challenges of climate change in the marine environment. Aquatic Conservation: Marine and Freshwater Ecosystems 27(S1): 6-29.

183. California Department of Fish and Wildlife and California Ocean Protection Council (CDFW and OPC). 2018. Marine Protected Area Monitoring Action Plan., California, USA. 302 pp.