Supplementary Report and International Case Studies

Best Practices and Procedures for Operationalizing Marine Protected Area Network Monitoring

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Introduction

This Supplementary Report provides detailed case studies, expert insights, and a literature review on best practices for operationalizing monitoring for marine protected area networks (MPANs). Insights from this report have been synthesized into a shorter report that includes best practices for MPAN monitoring and specific recommendations for an MPAN under development in the Northern Shelf Bioregion off the coast of British Columbia, Canada.

Marine protected area networks (MPANs) offer opportunities for habitat and species protection at large spatial scales while allowing for diverse human activities, including fishing, within a region. A major focus is to design the networks based on population-level and ecosystem-based understandings of marine areas (Maestro et al. 2019; Rassweiler et al. 2020; Grorud-Colvert et al. 2021; Sullivan-Stack et al. 2022). The anticipated benefits of MPANs include increases in biomass, abundance, and diversity of marine species. These benefits are achieved through a multi-dimensional approach to fisheries and marine conservation that can include features such as provision of refuges for harvested species and protection of habitats that are crucial for important lifecycle stages. Building ecological resilience through MPANs is also thought to lead to socio-cultural benefits such as food security, cultural values, stable resource bases for local communities, and employment in conservation related work (e.g., monitoring and stewardship).

Pursuing a network approach to MPAs, however, brings unique challenges and questions for ecological, environmental, and human dimensions monitoring (Grorud-Colvert et al. 2014; Hall-Arber et al. 2021). As MPANs are designed with the intent to protect representative habitats as well as unique and vulnerable areas and species, it is important to evaluate whether the group of protected areas are collectively contributing to these ends (Balbar et al. 2020). Some of the spatial features that make MPAN monitoring and evaluation unique include the diversity of habitats, prevalence of remote locations, and limitations on the ability to monitor numerous sites. These spatial challenges are further complicated by the prevalence of multiple types of protected areas and zoning that involve place-based and distinct governance arrangements, conservation objectives, and administration that involve multiple jurisdictions and partners. 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). .

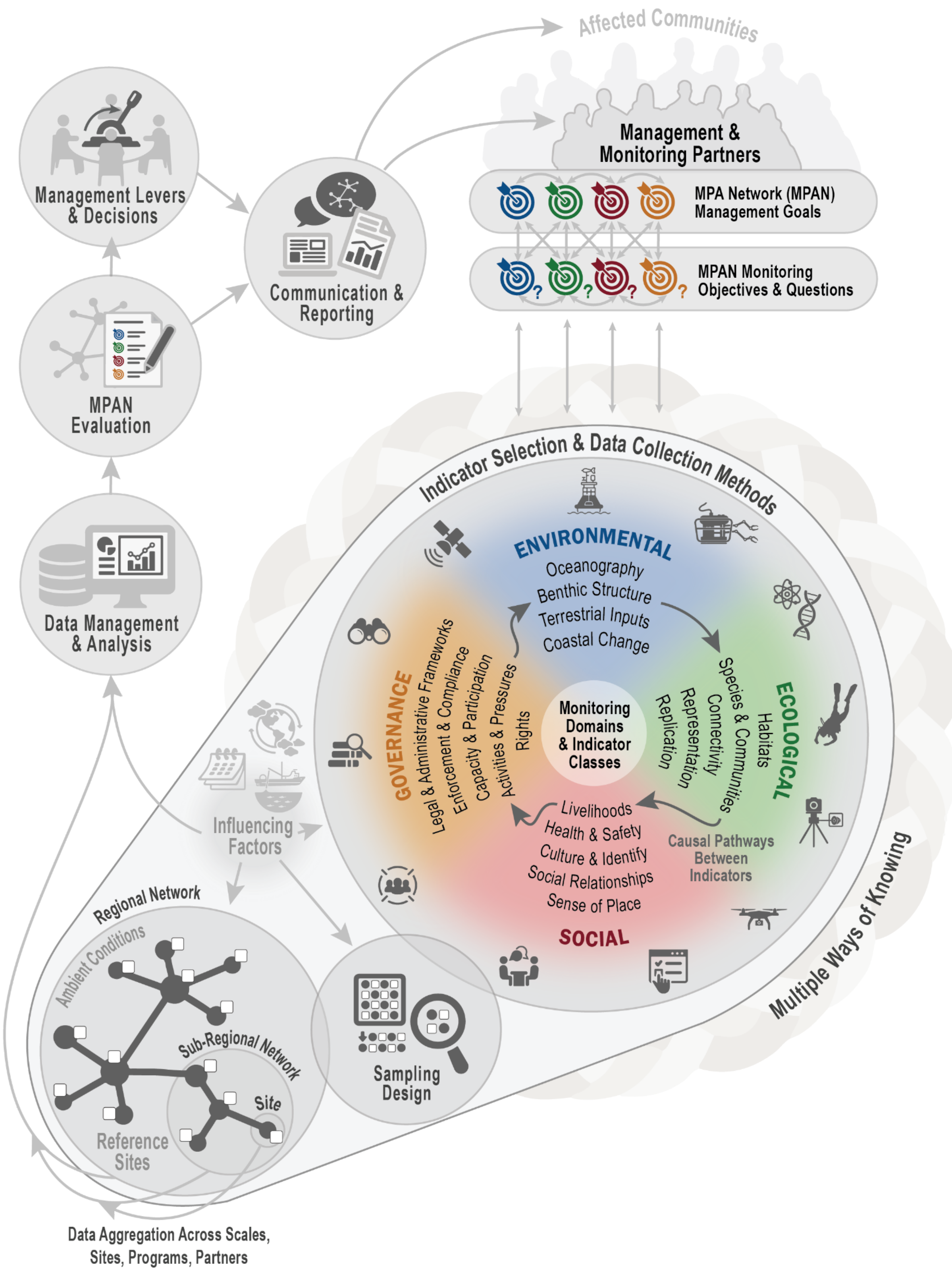


Figure 1: Overview of key elements of Marine Protected Area Network monitoring addressed in this supplementary report.

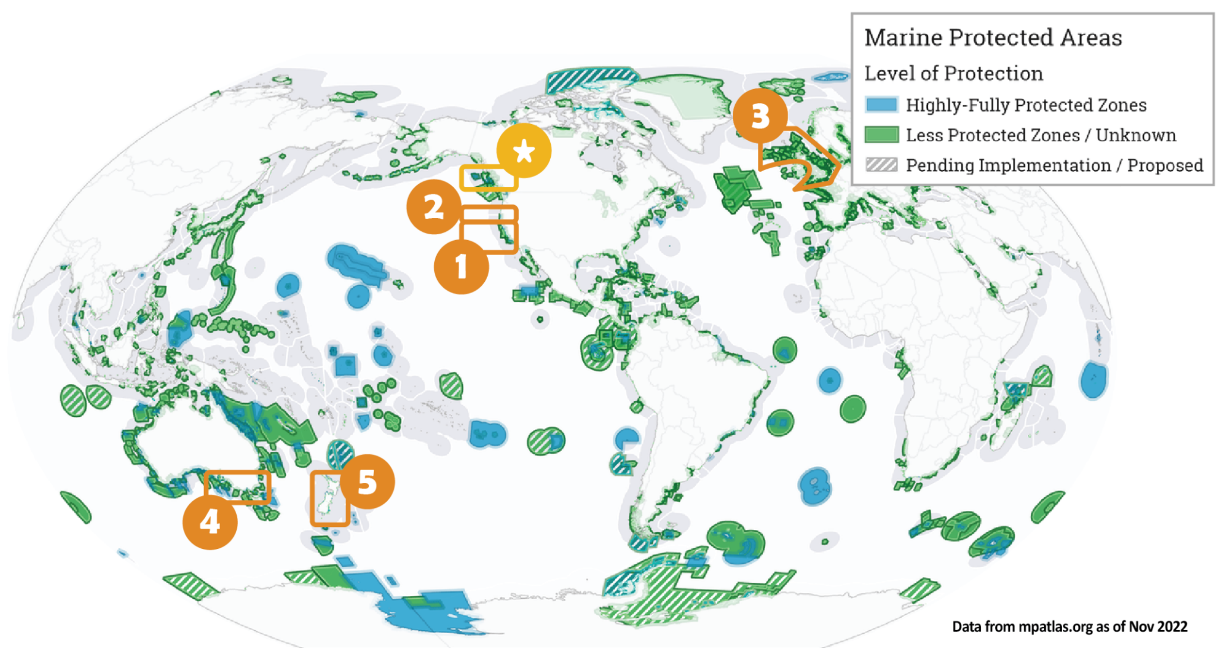
The purpose of this report is to identify global lessons and suggested best practices for operationalizing MPAN monitoring. Part one of the report consists of five case studies of MPANs, primarily from temperate regions that have documented their experiences with planning and operationalizing monitoring. These case studies draw on direct experiences from MPA managers and decision makers. Each case study synthesizes place-based lessons learned from MPAN monitoring and evaluation. Part two of the report is a detailed discussion of MPAN monitoring, based on a literature review and engagement with MPAN experts. This section includes discussion of 10 key topics ranging from early stages of developing monitoring plans to data collection to reporting for adaptive management.

Approach and Methods for this Report

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

In order to identify potential case studies of MPANs, we used a combination of expert knowledge, literature review, and internet searches. Seeking to learn from applied experience, we selected case studies where an MPAN had already been implemented or was in the process of implementation. In order to ensure that diverse yet relevant lessons could be drawn, we focused on case studies that (1) were within temperate oceans, (2) had elements of remote sites and monitoring, and (3) offered key lessons for both ecological and human dimensions monitoring. The selected case studies included MPANs in California (USA), Oregon (USA), United Kingdom, Victoria (Australia), and Aotearoa New Zealand (Table 1). Insights and lessons from each case study were developed through a combination of document review (e.g., monitoring plans and monitoring reports) and interviews with practitioners and experts with direct experience in MPAN monitoring design and/or implementation.

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

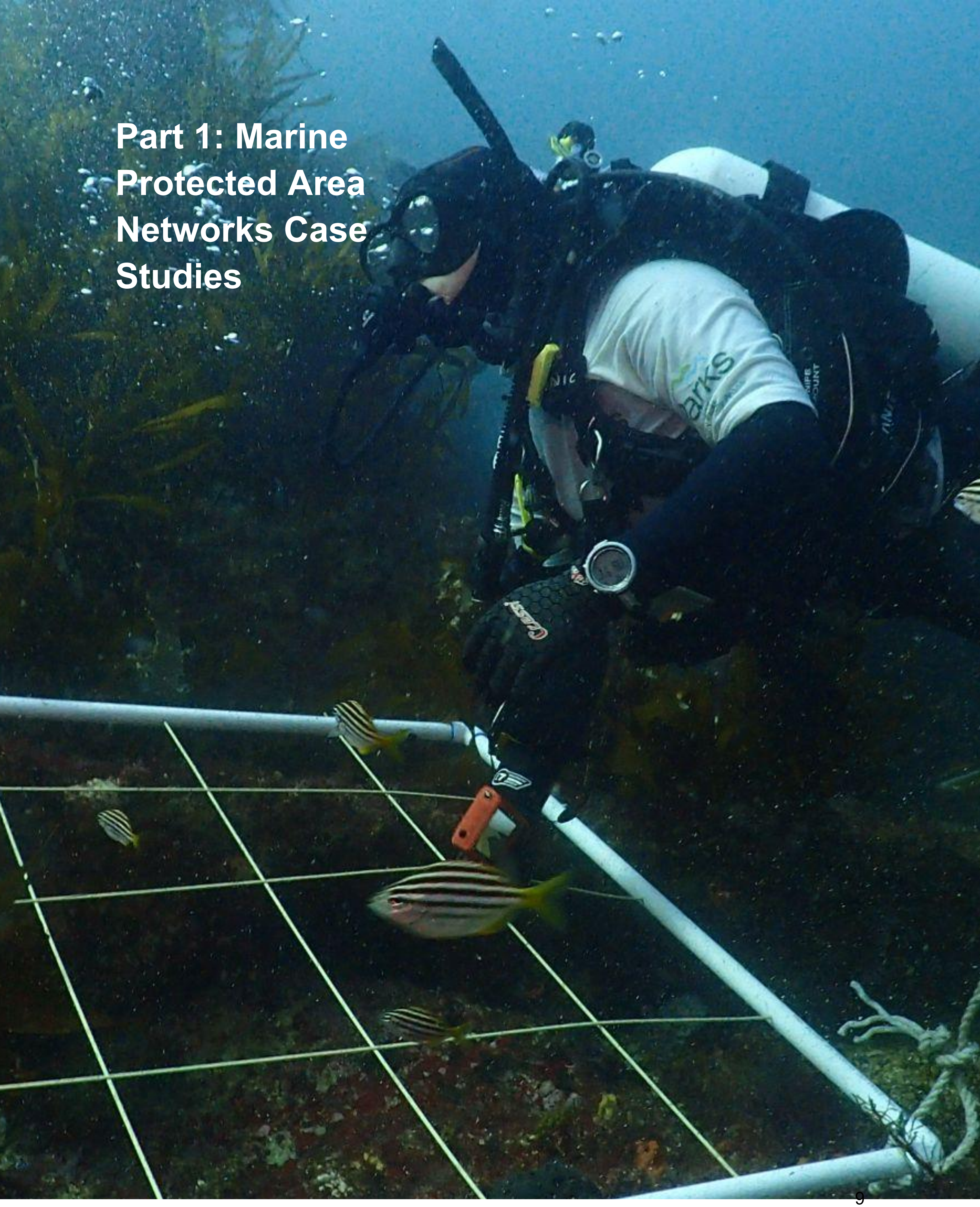


MPAN Location		Case Study Key Insights
1	California, USA	- Strong focus on network-level ecological monitoring - Thorough evaluations and reports for monitoring outcomes - Longer term monitoring lessons (10 years)
2	Oregon, USA	- Human dimensions monitoring - Longer term monitoring lessons (10 years)
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.

Information collected for Part 2 of the report was multifaceted to capture consistently used best practices as well as emerging technologies and approaches. Information sources included:

- Contributions and insights from the Advisory Committee.
- A targeted review of both peer-reviewed and grey literature focused on best practices for MPAN monitoring.
- A workshop that brought together international MPA monitoring experts and researchers working in the MPA space (Quadra Island, British Columbia, February 2023). This workshop focused on linking social and ecological dimensions of MPA monitoring (see workshop report in Appendix A).
- 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.

Part 1: Marine Protected Area Networks Case Studies



Beware Reef, Victoria, Australia © Parks Victoria

Case Study 1:

California MPAN Monitoring Program

Laguna Beach SMR, Credit: Steve Wertz

Key Lessons from this Case Study

A strength of California's MPA monitoring program is the mandate to monitor as a network
The inside-outside approach for monitoring - index sites within MPAs and paired reference sites outside of MPAs - has allowed researchers to answer a wide range of questions. Additionally, the focus on representative habitats across every region of the network has helped to enable network wide data collection and analyses.

Legislated funding for long-term monitoring is essential for consistent data collection
Legislated long-term funding can enable year-to-year budgeting and planning. While California has had some fluctuations in funding, there has been a base fund to support minimal monitoring. A tiered approach for deciding which sites to monitor has helped to ensure that consistent sites have been monitored (tiering focuses on site selection rather than which indicators or methods should be used).

Investment in understanding human dimensions of MPAs should begin early
A reflection and lesson from California's decadal review was that more emphasis should be placed on human dimensions monitoring. The lack of a plan for human dimensions monitoring has been recognized a gap that limits understanding of how changes related to MPAs impacts people and is impacted by people. To this end, it is essential to ensure that all key partners, Indigenous governments, industry stakeholders, and communities are engaged from the beginning of a monitoring program. This will help to ensure that everyone's interests are met and to leverage resources and expertise for monitoring that might be available.

Consider means and methods of integrating baseline and long-term monitoring
Think about baseline monitoring and long-term monitoring well in advance of their implementation. Linking both types of monitoring to MPAN goals, it can help with integration later on.

There is a need to manage trade-offs as MPANs cover very large areas
Decisions need to be made about monitoring as many sites as possible or monitoring fewer sites very thoroughly. California chose the latter to ensure consistent time series data (enabling stronger inferences, albeit for fewer sites).

Patience is needed to detect long-term positive outcomes
Even as California has completed its first decadal review, decision-making from existing data is still considered premature (e.g., more time needed for species with slower life history characteristics to show expected biological responses). 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).

In addition to the lessons identified for this case study, Table 2 lists further lessons compiled by the Resources Legacy Fund, as commissioned by Nature United in 2020.

Table 2: Lessons learned from California's MPAN Program (summarized from Resources Legacy Fund (2020).

Category	Lessons Learned
Importance of Monitoring	➢ Include explicit monitoring mandate ➢ Be realistic about tradeoffs in geographic scope and data quality ➢ Determine monitoring program scale— individual MPA or network? ➢ Clearly establish programmatic scope (ecosystem approach)
Monitoring Program Planning - *Baseline Monitoring (Phase 1, 2007-2018)*	➢ Baseline studies are long-term assets ➢ Include human dimensions monitoring ➢ Calibrate monitoring effort, expectations, and MPA management to local ecological conditions ➢ Share results and consider your audience
Monitoring Program Planning - *Long-term Monitoring (Phase 2, 2018 – ongoing)*	➢ Link monitoring to objectives ➢ Plan baseline and long-term monitoring in tandem ➢ Formally integrate existing monitoring efforts and avoid replication
Monitoring Partnerships	➢ Explicitly promote partnerships ➢ Be flexible ➢ Foster community science
Tribes and Indigenous Communities	➢ Tribes are critical partners ➢ Tribes contribute to our understanding ➢ Prioritize collaboration and partnership ➢ Ensure inclusive decision-making
Institutional Coordination	➢ Weigh options in deciding where to house monitoring program ➢ Build long-term institutional capacity
Data Storage and Management	➢ Design for durability ➢ Public accessibility should aim for "good enough"
Funding MPA Monitoring	➢ Establish stable, long-term funding ➢ Stretch existing funding through partnerships

Introduction

California's marine protected area network (MPAN) includes 124 individual MPAs and protects 16 percent (850 square miles) of the state's coastline. The Government of California's Marine

Life Protection Act (1999) initiated the design of the network. An extensive planning process from 2004 to 2012 involved stakeholder and expert input, policy development, and planning (Resources Legacy Fund 2020). The MPAN was implemented in 2012 and included six types of protected areas that have their own rules on allowable activities (Figure 2). These protected areas range from full closures that do not allow entry, to areas allowing recreational activities, to areas with restrictions on species extraction for scientific, commercial, or recreational purposes (Dawson 2023). The Marine Life Protection Act (MLPA) included six goals for the MPAN (Box 1), including that the State ensure “MPAs are designed and managed, to the extent possible, as a network.” This network approach to its monitoring program is a key strength - and somewhat unique globally.

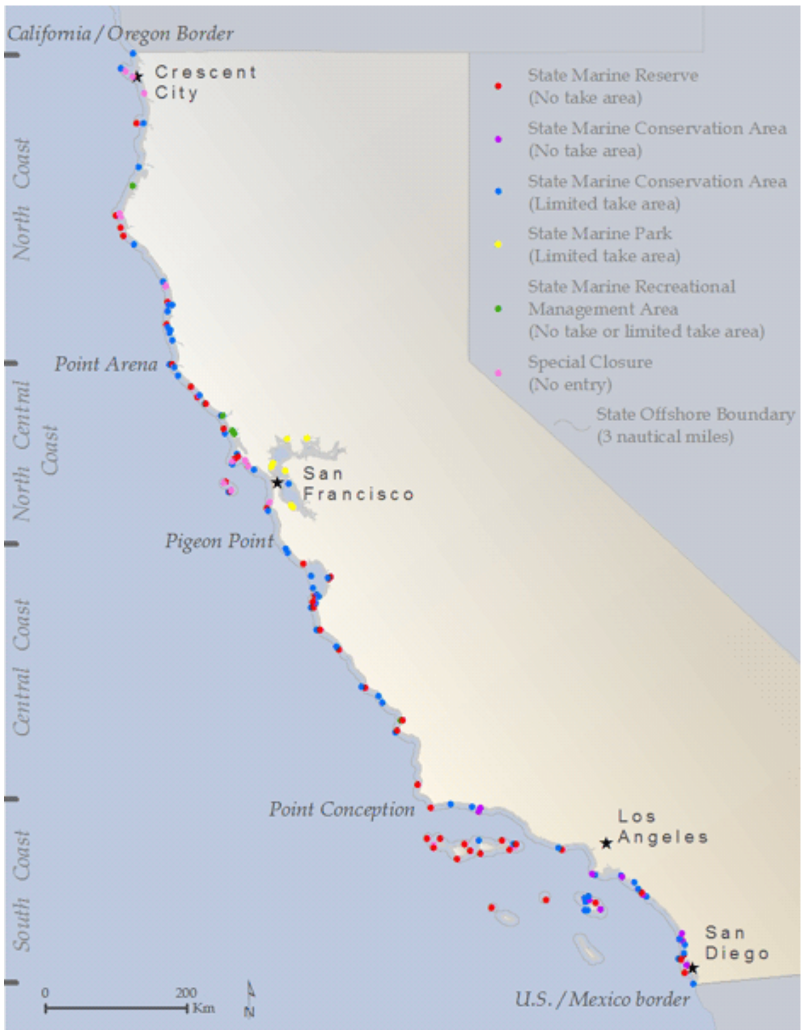


Figure 2: California Marine Protected Areas by type and location (Map from Marine Protected Area Monitoring Action Plan 2018).

BOX 1: Six goals included in the Marine Life Protection Act
(these goals do not have numerical thresholds that define success).

1. Protect the natural diversity and abundance of marine life, and the structure, function and integrity of marine ecosystems.

2. Help sustain, conserve and protect marine life populations, including those of economic value, and rebuild those that are depleted.

3. Improve recreational, educational and study opportunities provided by marine ecosystems that are subject to minimal human disturbance, and to manage these uses in a manner consistent with protecting biodiversity.

4. Protect marine natural heritage, including protection of representative and unique marine life habitats in CA waters for their intrinsic values.

5. Ensure California's MPAs have clearly defined objectives, effective management measures and adequate enforcement and are based on sound scientific guidelines.

6. Ensure the State's MPAs are designed and managed, to the extent possible, as a network.

While the MLPA includes requirements for monitoring, research, and evaluation to support adaptive management, annual funding has not always been consistent, which has led to some challenges for consistent long-term monitoring. The MPAN management program has received considerable public and private philanthropic support that have been essential for its long-term success (California Department of Fish and Wildlife 2022). On an annual basis, the monitoring program received a base of US$2.5 million from a General Fund that is then supplemented from other sources when available (Marine Protected Area Monitoring Action Plan 2018). Costs for overall planning and management of the MPAN were estimated at more than US$100 million between 2004-2022 (Van Diggelen et al. 2022), of which US$32 million in public funds supported monitoring programs (Resources Legacy Fund 2020).

The tiered approach to site monitoring - discussed in the following section - has helped to prioritize site selection when funding is insufficient. Additionally, California adopted a partnership-based approach that has helped to leverage supplementary funding and resources (Ocean Protection Council 2014; Resource Legacy Fund 2020). Partners for monitoring have included academic institutions (e.g., California Cooperative Oceanic Fisheries Investigations (CalCOFI); Multi-Agency Rocky Intertidal Network (MARINe)), community and citizen science programs (e.g., LIMPETS, MPA Watch; Reef Check California), and engagement with fisheries (e.g. California Collaborative Fisheries Research Project) (Meyer et al. 2022).

The California approach to monitoring integrates science, evaluation, and communication and is reflected in the core elements of the Marine Protected Area Monitoring Action Plan (Figure 3). Given the large geographic coverage of the MPAN, California has relied heavily on research consortiums of multiple institutions and organizations. These consortiums have typically been based on research and monitoring of habitat types (e.g., Rocky Intertidal, Kelp and Shallow Rock, Mid-depth Rock) instead of regions. Part of the intent of relying on consortiums has been to decentralize administrative burden, but also to support integration of monitoring across regions.

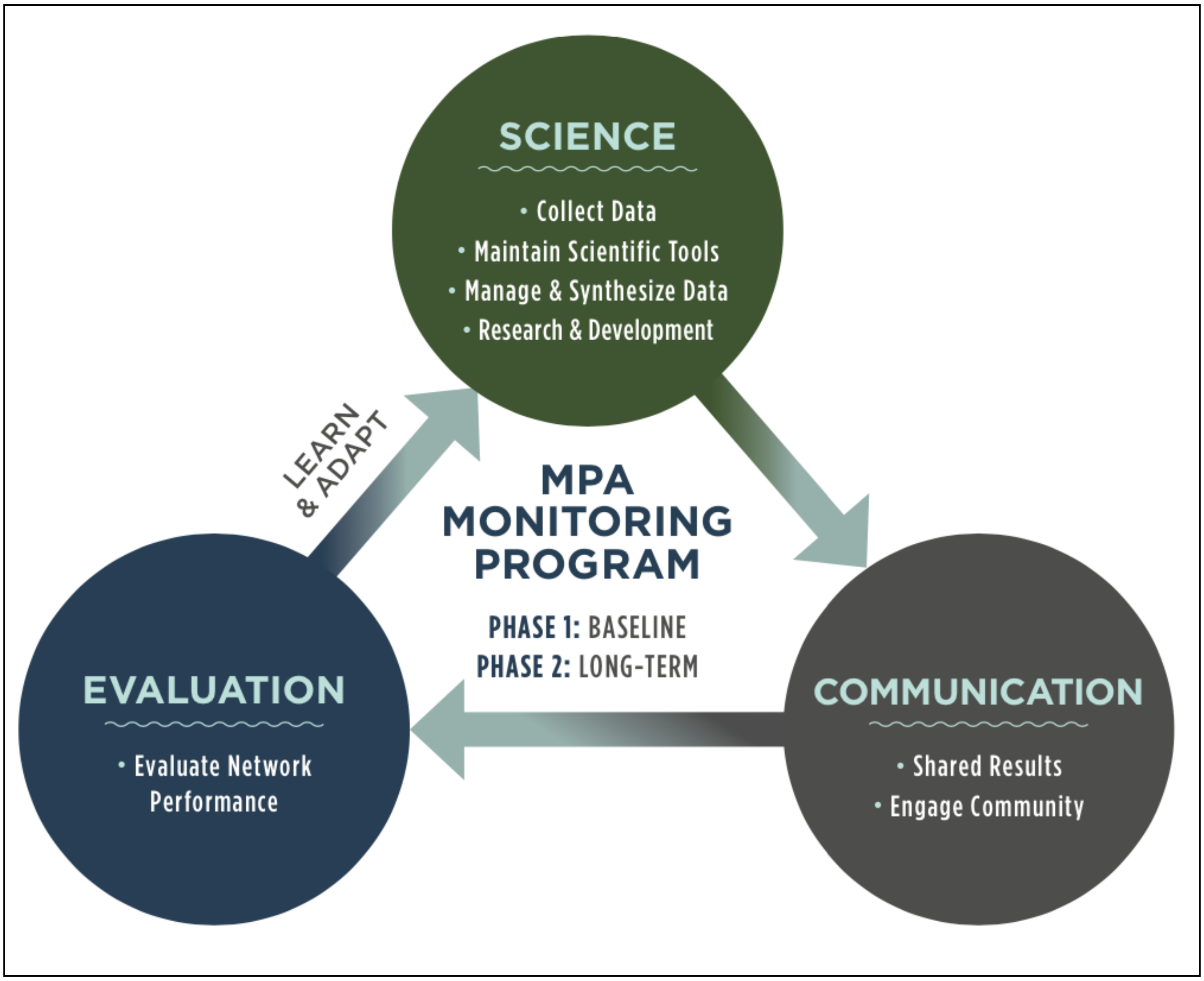


Figure 3: Core elements of the MPA Monitoring Program (source: Marine Protected Area Monitoring Action Plan 2018).

Evolution of MPAN Monitoring

Some scientists who were involved in the development of the MPAN in the 1990s advocated for the establishment of a monitoring program to be implemented with the MPAN. However, it wasn't until a draft Master Plan was adopted in 2008 that scientific guidance was released regarding the design and designation of MPAs. At this time, there was minimal guidance on monitoring, although the Master Plan called for the development of regional management plans and monitoring plans (Dawson 2022). Monitoring rolled out in two phases:

- Phase 1 - Baseline Monitoring (2007-2018)
- Phase 2 - Long-term Monitoring (2018 – ongoing)

Phase 1 involved region-by-region baseline monitoring and regional management plan development, while the ongoing Phase 2 focuses on thematic-based long-term monitoring. A brief history of monitoring implementation during these phases is presented in the remainder of this section.

Phase 1 - Baseline Monitoring (2007-2018)

Four MLPA planning regions were identified based on their unique characteristics within the larger statewide MPAN (Marine Protected Area Monitoring Action Plan 2018). Implementation was carried out region-by-region (Table 3), where management plans were tailored for each region. This process for developing regional management plans included baseline data collection within each region. Baseline data collection focused on the following habitats and human uses:

- Habitats
  - Rocky Intertidal
  - Kelp and Shallow Rock (0-30 m)
  - Mid-depth Rock (30-100 m)
  - Soft-bottom Intertidal and Beach
  - Soft-bottom Subtidal (0-100 m)
  - Deep Ecosystems and Canyons (>100 m)
  - Nearshore Pelagic (i.e., the water column within state waters 0-3 nm)
  - Estuaries
- Human uses
  - Consumptive Human Use
  - Non-consumptive Human Use

Public and political pressure to commence monitoring meant that the California Department of Fish and Wildlife (CDFW) was challenged in their ability to create a coordinated, network-level monitoring plan (Dawson 2022). A major concern noted by Dawson (2022) was that indicator selection emphasized projects that maximized the amount of data collected, while issues around integration across the MPAN were set aside to be addressed at a later stage.

> "*A core issue that plagued the Regional Monitoring Plans was the approach identified the species and metrics to monitor then subsequently pointed out what questions could be answered by the data collected. This is a fundamental reversal of the standard scientific approach for designing monitoring programs which identifies the questions to be answered, the sensitivity needed to answer the question, then uses established statistical procedures to design the appropriate monitoring*." (Dawson 2022, p.7)

Table 3: Timing for development of regional management plans and Phase 1 collection of baseline data (adapted from Dawson 2023).

Coastal Region	Date Implemented	Baseline Data Collection Period	Analyze, Synthesize, & Share Baseline Information
CENTRAL (Pigeon Pt. to Pt. Conception)	September 2007	2007 - 2010	2010 - 2013
NORTH CENTRAL (Alder Creek to Pigeon Pt.)	May 2010	2010 - 2012	2012 - 2016
SOUTH (Pt. Conception to US/Mexico Border)	January 2012	2011 - 2013	2013 - 2017
NORTH (California/ Oregon border to Alder Creek)	December 2012	2016 - 2018	2013 - 2016

Phase 2 - Long-term Monitoring (2018 – ongoing)

The updated Master Plan was adopted in 2016 with the intent of better aligning with and meeting the goals of the MLPA. Subsequently, a MPA Action Plan was released in 2018. To better link monitoring metrics to long-term management goals, the Action Plan translated the six MPAN goals into monitoring objectives, and then translated those into questions and hypotheses (Appendix B of the Action Plan). By focusing entirely on MPA monitoring, the MPA Action Plan differs from earlier reports. The Action Plan was the first attempt to identify priority sites and metrics, although it still did not integrate data collection and analysis across habitats and between baseline and long-term monitoring (Dawson 2022).

The Action Plan was based on a combination of expert input and review of the regional management plans and established a plan for long-term monitoring based on specific metrics (e.g., density, abundance, size, biomass, and diversity of species), habitats, sites, species, and human uses (Dawson 2022). Sampling protocols for seven thematic areas were initiated for long-term monitoring:

- Surf zone/Sandy beaches
- Rocky intertidal
- Kelp forest/shallow rocky reef
- Mid-depth rock - Collaborative Fisheries Research Program
- Mid-depth rock - ROV/HOV/Landers
- Oceanographic
- Socioeconomic

The sampling protocols specify a preference for sampling both inside an MPA and at a comparable outside-MPA reference site (e.g., with similar habitat and species composition). This protocol aimed to support evaluation of the MPAN's performance with respect to network goals. The Action Plan also changed the number of regions from four to three (north, central, and south) based on clusters of similar biota, ecological communities, and key habitats. Data collection for each of the thematic areas spans across the three regions, although to date they do not all have the same time series available (Dawson 2023).

The Marine Protected Area Monitoring Action Plan (2018) set out priorities for key performance measures and metrics. These measures and metrics were categorized according to species-level, community-level, physical environment, chemical, and various human uses (Table 4) in order to support long-term evaluation against goals of the MLPA. Selection of the measures and metrics was based on a global review of MPA performance studies.

Table 4: Key performance measures and metrics (compiled from Marine Protected Area Monitoring Action Plan 2018).

Dimension	Measures
Species-level	• Abundance • Density/cover • Size/age frequency • Biomass
Community-level	• Functional diversity (tracking the population dynamics of those species and organismal traits that influence ecosystem functioning) • Stability
Physical	• Temperature • Depth • Substrate (e.g., rock or sediment size, type, and rugosity) • Wave exposure
Chemical	• pH • Total alkalinity • Dissolved oxygen
Human Use - Commercial Passenger Fishing Vessel	• Annual license renewal and vessel registration • Port of departure • Number of anglers • Target species • Trip length • Fishing location • Average price paid per angler • Number and pounds of fish caught by species

	• Number of crew on trip • Effort and catch per unit effort (CPUE) • Annual operating costs • Number of crew employed
Human Use - Commercial Fisheries	• Annual license and vessel renewal • Number of fishermen making landings • Landings: catch, price, and revenue by species • Gear type • Landings port location • CPUE • Harvest location • Annual operating costs • Number of crew employed
Human Use - Recreational Fisheries	• License purchases • Catch amount • Catch location • Catch effort • Type of gear/mode
Human Use - Coastal Recreation and Tourism	• Location of residence • Demographic information (i.e. age, gender, education, etc.) • Income • Employment status • Frequency and type of visit • Location of visit • Type of activities • Trip expenditures
Human Use - Enforcement (location specific)	• Patrol hours • Citations • Warnings • Cal TIPs received related to potential MPA violations

As stated above, the general approach for evaluating the response of metrics (e.g., density or biomass) is to replicate data collection at paired sites inside (index) and outside (reference) protected areas. The outside sites are meant to have similar environmental and ecological characteristics so that differences in variability can be compared over time. Selection of monitoring sites was based on a tiered system. Given logistical and financial infeasibility to monitor all MPA sites and associated reference sites, the Action Plan set three tiers for long-term management and monitoring:

- **Tier I (required)** - "They meet many of the design criteria needed for effective protection, are well connected components of the MPAN, and may have long time series of monitoring data and/or have experienced high historical fishing effort, which make these MPAs good candidates for detecting the potential effects of protection over time. Many of the MPAs on the Tier I index site list are state marine reserves, which were designated during the design process to be the backbone of the network (CDFW 2016), thus providing "an improved marine life reserve component consistent with the guidelines for the preferred siting alternative" (FGC §2853(c)(1))."

- **Tier II (secondary)** - "Many of these MPAs ranked high in one or two of the quantitative methods and may be considered valuable index sites for more specific research questions. Tier II MPAs can be considered for long-term monitoring when funding permits, when an MPA cluster is split between tiers, or to help answer more regionally focused questions."
- **Tier III (tertiary)** - "While valuable to the Network's integrity, many of these MPAs are limited for monitoring purposes at this time due to features such as smaller size, fewer representative habitats, are difficult to access, have limited or no long-term monitoring data, or have more allowable take within their boundaries. Tier III MPAs are recommended for long-term monitoring only to answer very specific or localized research questions."

Categorization of sites into the tiers was based on analysis of baseline monitoring[1]. The Action Plan emphasizes that these tiers do not infer relative importance of individual sites or MPAs - they are intended to reflect how well they align with the quantitative criteria for each tier. MPA managers and partners are instructed to prioritize Tier I index sites that align with project monitoring methods, and to also monitor Tier II and III sites when feasible.

The process for selection of reference sites outside of MPAs was also laid out in the Marine Protected Area Monitoring Action Plan. Rather than specify specific reference sites, the Action Plan lays out criteria for selecting appropriate sites. In order to ensure that inside/outside comparisons are meaningful, monitoring partners are instructed to use the following criteria and quantitatively assess compatibility with index sites (Marine Protected Area Monitoring Action Plan 2018). These criteria and suggested metrics are summarized in Table 5.

Table 5: Criteria to identify reference sites outside of MPAs (compiled from Marine Protected Area Monitoring Action Plan 2018).

Category	Criteria	Suggested Metrics
Biotic Factors	Ecological conditions at the time of MPA Implementation	functional biodiversity, species composition, species density and biomass, size frequency distributions
Human Uses	Fishing pressure at time of MPA	local fishing mortality for targeted species, historical fishing

[1] The analyses that lead the designation of sites within the three tiers was based on four criteria (MPA Design Features, MPA Historical Monitoring, Habitat Based Connectivity, and High Resolution Mapping of Recreational Fishing Effort). The scoring and analytical approach are detailed in the Marine Protected Area Monitoring Action Plan (2018), pages 22-25 and Appendix F.

	implementation	effort, regional proxies for fishing effort (e.g., distance from port)
	Non-consumptive human use	type and level of non-consumptive use (e.g. from MPA Watch beach surveys), water quality, frequency of boat anchoring
Abiotic Factors	Geography	presence of biogeographic barriers, distance between MPA and reference sites
	Habitat features	depth, percent rock, rugosity, habitat complexity, macroalgal cover, distribution of habitat types
	Geology	underlying rock type (e.g., shale, granite), grain size, benthic community structure, proximity to major geologic features such as submarine canyons
	Physical and chemical oceanography	primary productivity/nutrient availability, wave exposure (including direction, extent, and intensity), and variability and spatial distribution of relevant dynamics and processes, such as upwelling, fronts, river plumes, ocean acidification, hypoxia

Network Analyses and Adaptive Management

To support analysis of long-term monitoring of the California MPAN, ten consortium projects were selected based on a competitive proposal process and informed by the baseline monitoring results. The monitoring portfolios for the currently funded consortia (Table 6) reflects the continuation of the habitat rather than regional approach to monitoring and evaluation. California recently launched a MPA Monitoring Data Portal as a publicly available repository. An aim of the portal is to make scientific MPA data more accessible for everyone by housing all monitoring documents and datasets available in one place.

Table 6: Projects and institutions selected to support long-term evaluation.

Monitoring Portfolio	Lead Institution
Rocky intertidal habitats	University of California (UC) Santa Cruz
Kelp forest/shallow rocky reef habitats	UC Santa Cruz
Deep rocky reef habitats	San Jose State University
Sandy beach/surf zone habitats	UC Santa Barbara

Socioeconomic monitoring program for consumptive human uses	Ecotrust
California Collaborative Fisheries Research Program (CFRP)	San Jose State University
Integration of oceanographic data	California Ocean Observing Systems
Assessment and monitoring of California’s estuaries	San Jose State University Research Foundation
Development of model-derived connectivity metrics for the assessment	UC Santa Cruz
Development of a Tribal Marine Stewards Network pilot program	California Indian Environmental Alliance (CIEA)

In addition to each consortium producing reports and publications, a number of broader network analytical efforts have been underway. **While California is a global leader in taking a network approach to MPAs, experts consulted for this case study indicated that they are still learning what it means to monitor and evaluate on a network level**. A critical question that scientists involved with the monitoring program have asked is what differentiates monitoring and evaluation for the MPAN as a whole from monitoring individual MPAs. How might it be possible to detect the conditions of network-level ecological functions? Larval connectivity between kelp forests has been a novel approach that has yielded promising results for near-shore animals (Carr et al. 2017, 2021). On the other hand, recent modeling work has not been able to replicate this approach for juvenile animals that spawn in deeper waters. What this ultimately means for the California MPAN is that connectivity and movement between habitats is understood for some species but not others. There is an incomplete understanding of how specific species are using areas and habitats along California’s coast.

The Marine Protected Area Monitoring Action Plan (2018) also included several examples of network analyses that have been under development. These analyses focus on:

- Projecting Changes And Their Statistical Detectability Following MPA Implementation
- Incorporating Spatial Differences in Fishing Mortality to Project Population Responses to MPAs
- Estimating the Time Frame of Response for Different Species
- Informing Long-Term Monitoring Sampling Design

The intent of these types of analyses is to feed into improved long-term monitoring and decision-making for adaptive management (Figure 3). To date, the **adaptive management process** has led to several legislative and regulatory amendments (California Department of Fish and Wildlife 2022). 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).

Regulatory amendments have included clarification on regulations related to seasonal closures and special closures, as well as updated boundaries to be in line with ancestral tribal areas.

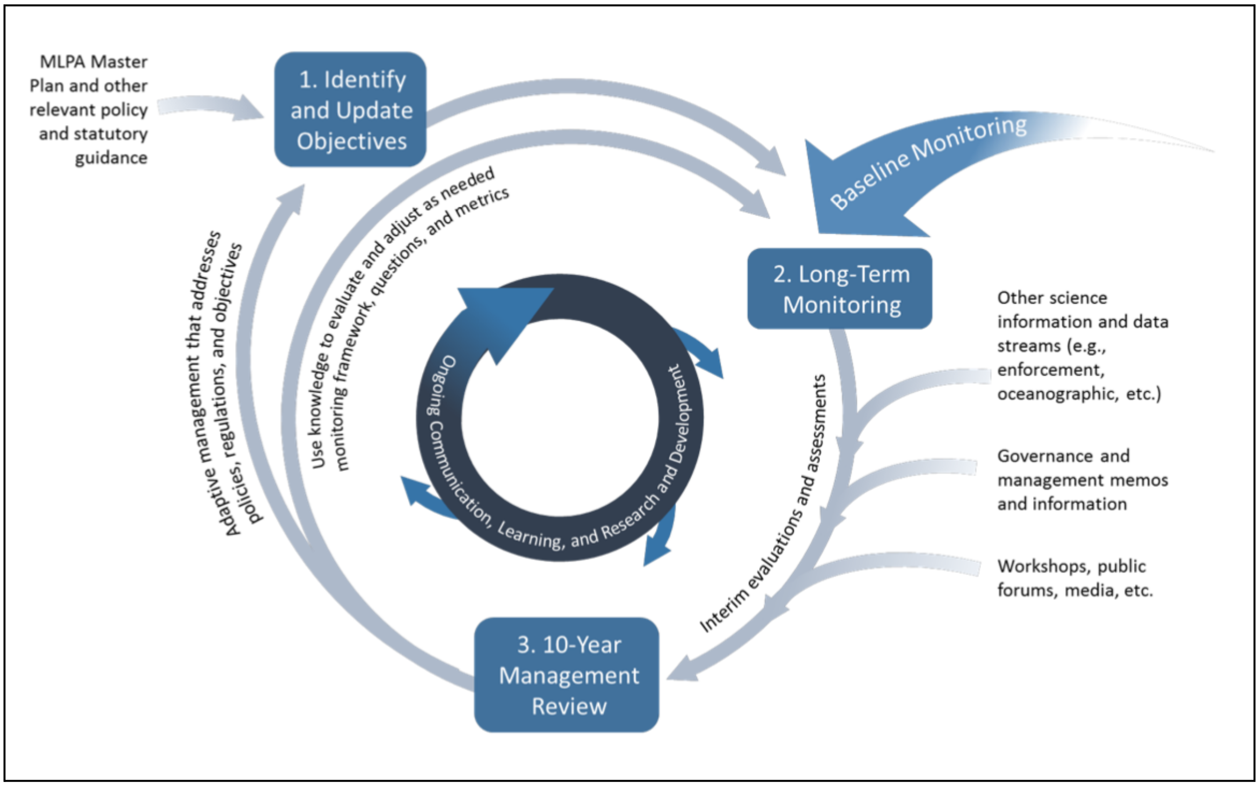


Figure 4: Adaptive management process for the Marine Life Protection Program (from California Department of Fish and Wildlife 2016).

Decadal Review

Following the 2008 draft Master Plan, a series of 5-year management reviews were conducted for each region to ensure that management plans were being implemented in ways that support the network goals (Dawson 2022). The results of these reviews led to the 2016 Master Plan prescribing a 10-year management for the entire network (California Department of Fish and Wildlife 2016). The decadal review was initiated in 2022 and considered ecological, socioeconomic, and governance aspects of the network to inform the adaptive management process. A series of reports have emerged from the decadal review that help to evaluate network performance (Table 7). As the Master Plan did lay out guidance for the decadal review, the report prepared by Hall-Arber et al. (2021) set out recommendations and scientifically tractable questions to guide the network-wide evaluation.

Table 7: Key reports from the California MPAN decadal management review.

Report	Authorship	Focus of Evaluation
Scientific Guidance	Hall-Arber et al. (2021)	➢ Provide quantitative, tractable scientific

for Evaluating California's Marine Protected Area Network	➢ Report by the Ocean Protection Council Science Advisory Team Working Group and California Ocean Science Trust	questions that can reasonably be assessed at the 2022 management review and in future decadal evaluations ➢ Provide scientific definitions of selected terms in the MLPA ➢ Provide methods for integrating baseline MPA monitoring, long-term MPA monitoring, and other available data streams ➢ Provide appropriate approaches for answering network-wide evaluation questions ➢ Identify significant gaps in understanding MPA performance in California and recommend monitoring approaches to fill those gaps
California's Marine Protected Area Network Decadal Management Review	California Department of Fish and Wildlife (2022) ➢ Included contributions from California Department of Fish and Wildlife and California Ocean Protection Council	➢ Components of the review included: MPA Management Program Framework; Research, Monitoring, Science Guidance; Tribal Coordination; Stakeholder and Partner Coordination; and California Department of Fish and Wildlife Cross-Project Coordination
A Synthesis of Ecological and Social Outcomes from the California Marine Protected Area (MPA) Network	Caselle et al. (2022) ➢ Working group coordinated by National Center for Ecological Analysis and Synthesis (NCEAS)	Social and ecological analyses using a diverse set of available monitoring data that address critical MPA performance evaluation questions ➢ Four aspects of MPA evaluation: Ecological Performance, Habitat, Climate Resilience, and Human Engagement ➢ Includes recommendations based on each focal aspect

As MPAs are designed to influence human behaviours and reduce human pressures on ecosystems, approaches to monitoring may look at changes in those pressures (e.g., fishing effort in and around MPAs) or changes in response variables. The California experience has shown that the **amount of fishing pressure that occurred before implementation of MPAs and the duration that an area has been under protection strongly influence the observable outcomes** (Murray and Hee 2019; Nickols et al. 2019). Species that were more heavily fished are more likely to respond quickly to conservation measures, which informs expectations about species-specific outcomes from MPAs and the MPAN as a whole (Dawson 2023). Another important insight of the decadal reviews is that long time series (i.e., longer than 10 years) are required to see meaningful changes for most species.

Another consistent message from the decadal review reports was that California needs to improve human dimensions monitoring. Needed improvements include more engagement with human dimensions experts and with Tribal governments. An updated monitoring plan with more human dimensions performance metrics is due to be finalized by late 2023. Already the [Tribal Marine Stewardship Network] - which was largely inspired by the [Indigenous Guardians program] in Canada - is being engaged more through listening sessions to learn more about how Tribes are already doing their own monitoring and looking for opportunities to work towards co-management. Another emphasis in the decadal review was the need for improved social-ecological integration for monitoring. The Ocean Protection Council Science Advisory Team Working Group conceptualized a social-ecological framework which emphasizes interconnectedness of ecological, governance, and human domains of the MPAN (Figure 5). The idea of adopting a social-ecological systems framework is to foster a broad and holistic understanding of the interconnected MPAN.

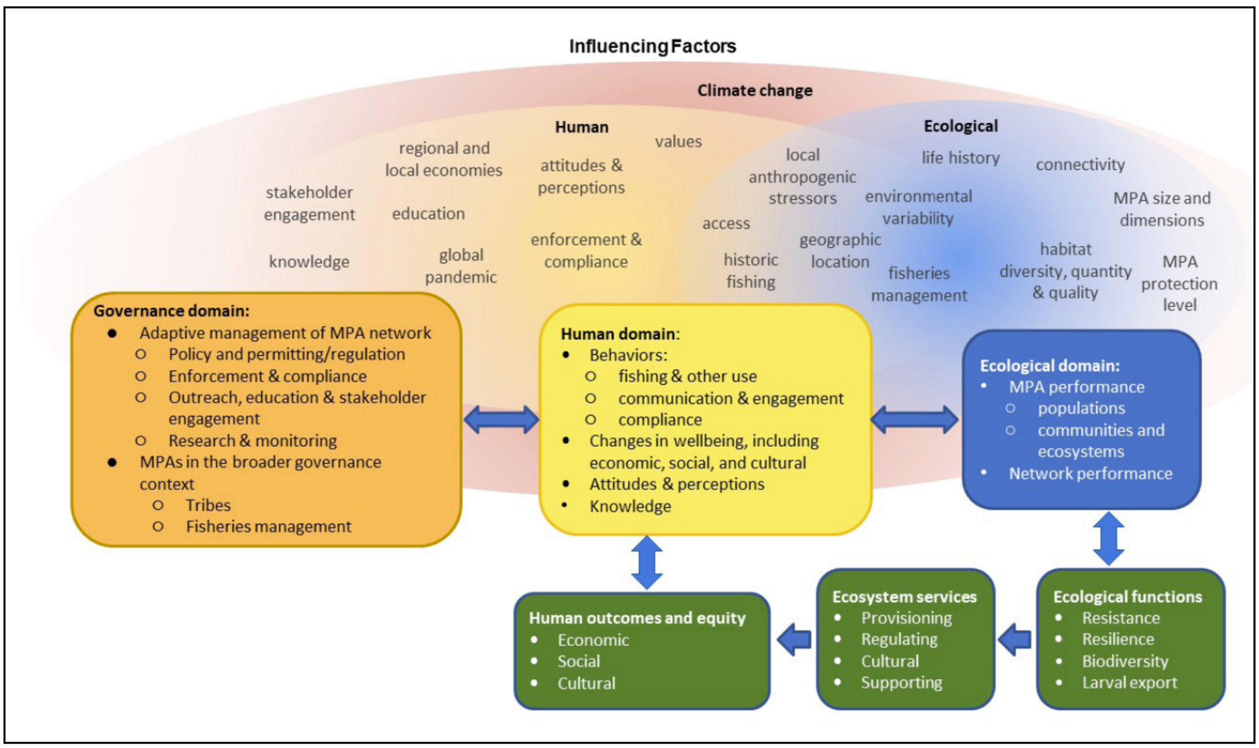


Figure 5: Social-ecological framework developed for decadal management review (from Hall-Arber et al. 2021).

Another key reflection from the decadal review is that implementation of the monitoring program happened relatively fast. Baseline data collection took a number of years to complete but the rollout of long-term monitoring began before there was a full appreciation of what it means to monitor the network as a whole. For example, as it became clear that it would not be possible to monitor all relevant species and habitats (for practical and financial reasons), the monitoring planning process shifted from a species to a habitat focus and from 13 habitats down to 7 habitats. The current focus on habitats is what ties the network monitoring together. The experts who we consulted with also emphasized that the iterative learning process has also been important. While they lamented initial stumbles with data collection, now that more data are available it is possible to use new analytical methods to answer different questions and there is a greater appreciation of the value in tying monitoring goals to the larger MPAN goals.

Case Study 2:

Oregon Marine Reserves Human Dimensions Research Program

The Oregon case study was authored by Cristen Don (Swell Consulting)

Community outreach, Credit: ODFW

Key Lessons from this Case Study

Experienced Human Dimensions Scientist Directing Research is Critical to Success
Having a senior human dimensions scientist on staff, with experience in applied research programs, was critical to establishing and conducting a robust human dimensions research program. This level of expertise was necessary to coordinate partners and to ensure that products provided to Oregon Department of Fish and Wildlife (ODFW) were applicable and useful to resource managers and decision makers. It has been ODFW's experience that human dimensions research conducted by a non-specialist or by less experienced personnel have resulted in inapplicable research outputs.

Look Beyond Marine Institutions to Find Human Dimension Academic Research Partners
Academic researchers with expertise in the human dimensions of natural resources are often not housed within marine institutions. For example, the majority of ODFW's academic social science research partners were in departments/schools of Tourism and Recreation, Forestry, Public Policy, Anthropology, and Psychology.

Long-term Collaborations are Key to Applied Research and Long-term Monitoring
Building long-term relationships with research partners helped ensure continuity in data sets (important for long-term monitoring), and produced meaningful contributions to an applied research and management program.

Working With Partners is Often Essential to Success but Comes With Challenges
The additional capacity, funding, and expertise brought by partners is often essential to the success of MPA implementation. While the ODFW Marine Reserves Program is focused and held to implementation of the marine reserve sites and mandates, their partners often have additional obligations, mandates, and incentives beyond that of the marine reserves. For example, academic partners may be incentivized to focus on novel research methods, providing research experiences for students, or publishing their findings in a peer reviewed journal which may not always be pertinent or timely to an applied research and management program. ODFW found that building collaborative partnerships and projects requires time, frequent interactions, and consistency in personnel to build relationships and projects that meet the needs of both ODFW's program and the partner, and meaningfully contribute to an applied research and management program. Clearly defining roles and responsibilities, and initial establishment of firm goals for data management and deadlines for deliverables or final reports, provides a strong foundation for the success of collaborations (ODFW 2022).

Core Funding and Staff are Necessary for Attracting Additional Resources
Without core state funding and staff, ODFW would lose the ability to attract partners and additional grant funds. State funding and staff demonstrate a commitment by the state, allowing ODFW to provide seed money to partners for projects which partners can then leverage, and allow ODFW to provide sufficient match for grants sought by ODFW or partners. (ODFW 2022).

Research that Brings a Voice to Impacted Individuals is Important
ODFW found that qualitative interview research projects with individuals who are perceived to be negatively impacted either economically or socially by the reserves helped build trust, particularly within the fishing community. These types of research projects uncover impacts that would otherwise not be detected by other methods and provide a way for individuals or small groups of people to share their lived experience and feel heard. This research was largely carried out by one of ODFW's partners in anthropology. See this "Reserves News" post on some of the lessons learned from qualitative interviews with commercial and charter fishers.

Introduction

Socioeconomic (human dimensions) research and monitoring of Oregon's marine reserves has been ongoing for over a decade. This report provides an overview of the development and implementation of the Human Dimensions Research Program established by the Oregon Department of Fish and Wildlife (ODFW) as part of the long-term monitoring of Oregon's marine reserve system. The report also highlights lessons learned from the program that may be of value and most applicable to the start up and implementation of other MPA or long-term human dimensions monitoring programs.

Preparation of this report was based on personal experience and communications with ODFW Marine Reserves Program staff, research partners, and advisors between 2009-2022, as well as the Marine Reserves Program Synthesis Report: 2009-2021 (ODFW 2022), Human Dimensions Research Technical Appendix (Swearingen and Fox 2022), and University Assessment Report (Hopf et al. 2022a) all produced as part of the recent decadal review of Oregon's Marine Reserves Program.

Background: Oregon's Marine Reserves

Oregon's Marine Reserve System
In 2012, after a decade of planning, the state of Oregon, USA completed the designation of five marine reserve sites (see map). All five sites have at their core a marine reserve where all extractive activities, including fishing and ocean development, are prohibited. Most of the sites also include one or more, less restrictive Marine Protected Area (MPA) adjacent to the reserve. All five of the sites are located within Oregon state waters (0-3 nautical miles from land). The sites are managed as a system[2] by the State of Oregon. The Oregon Legislature appointed ODFW as the lead agency responsible for overseeing the management and scientific monitoring of Oregon's marine reserves.

[2] Oregon has defined a "system" as a collection of individual sites that are representative of marine habitats and that are ecologically significant when taken as a whole (OPAC 2008). Oregon's marine reserves were not designed to function as a scientific network.

Oregon's Marine Reserve Goals
The goals for Oregon's reserves are to conserve marine habitats and biodiversity; to serve as scientific reference sites to support nearshore management and the adaptive management of marine reserves; and to avoid significant adverse social and economic impacts on ocean users and coastal communities (OPAC 2008).

Legislation And Policy Guidance

Mandates for marine reserves planning, designation, and implementation - including mandates for socioeconomic research - were set by the Oregon Legislature in House Bill 3013 (passed in 2009) and Senate Bill 1510 (passed in 2012). The goals and objectives for Oregon's marine reserves, along with planning and implementation principles and guidelines, are laid out in *Oregon Marine Reserve Policy Recommendations* developed by the Oregon Ocean Policy Advisory Council (OPAC)[3] in 2008.

The Odfw Marine Reserves Program

The ODFW Marine Reserves Program was established in 2009 by the Oregon Legislature, providing state funding and staff dedicated to supporting marine reserves planning and implementation. The program is responsible for overseeing the management and scientific monitoring of Oregon's marine reserve system.

Staff And Partners

The program includes a six-person interdisciplinary team responsible for ecological monitoring, social and economic (human dimensions) research, outreach, community engagement, development of site management plans, and providing support for compliance and enforcement of Oregon's marine reserves. The program shares management responsibilities with three other state agencies and works with a variety of partners and contractors from academia, the fishing industry, the private sector, non-governmental organizations, and local marine reserve community groups to carry out many aspects of marine reserves implementation (Figure 6).

[3] OPAC is a legislatively mandated body that advises the Governor, state agencies, and local governments on marine resource policy issues in Oregon.

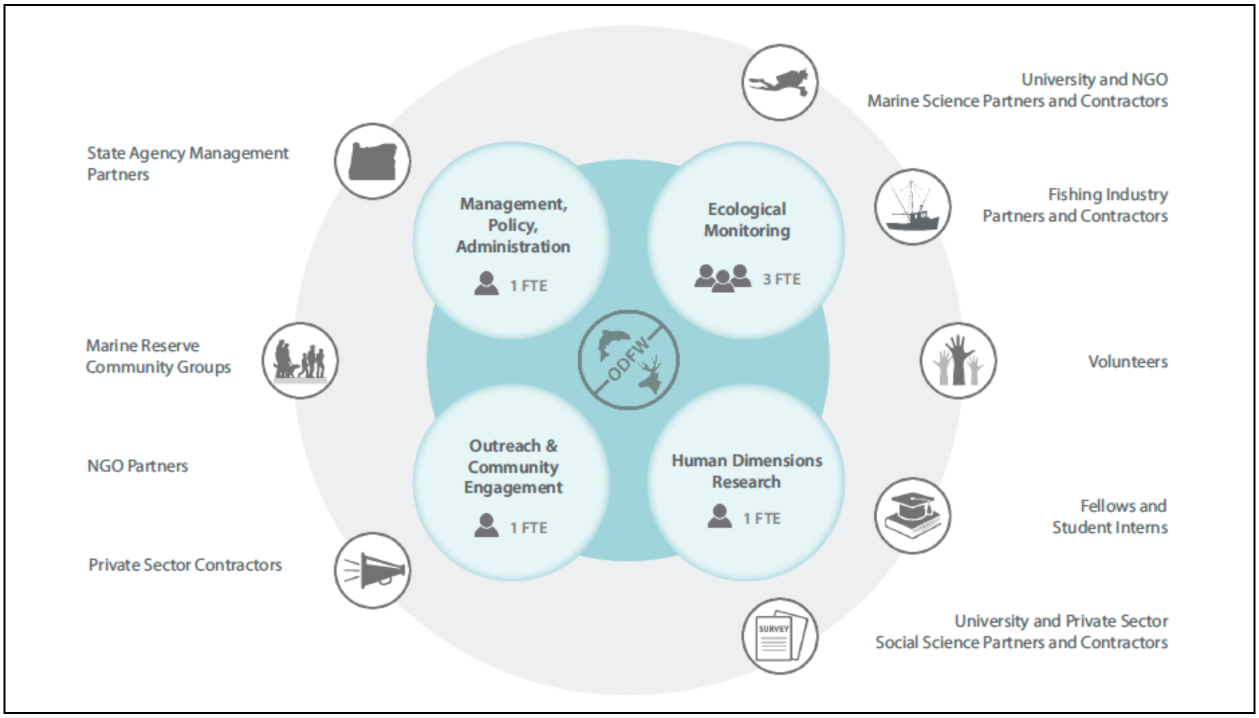


Figure 6: Structure of the Oregon Marine Reserves Program (from ODFW 2022). Implementation of Oregon's marine reserves is carried out through a centralized management structure led by ODFW.

Budget

The program's biennial (two-year) budget is approximately USD$1.8 million and is primarily funded through the state's General Fund (state tax dollars). The program also leverages state resources through grants, partners, and contracts. While much of the work is carried out internally by program staff, a substantial portion of state funds are directed to partners, contractors, students, and postgraduate fellows to carry out many aspects of work.

First 10 Years: Program Development And Operationalization

Marine reserves are a relatively new management tool in Oregon. The first 10 years was primarily focused on developing and operationalizing this nascent, long-term nearshore conservation and monitoring program. Central to this initial implementation phase was learning and adapting by the program along the way. In the first five years ODFW focused heavily on supporting marine reserves planning and designation as well as developing, testing, and adapting monitoring protocols and tools; building collaborations with partners; and finding ways to navigate and streamline complex funding, staffing, and contracting administrative procedures.

Program Assessment And Report To Legislature

As part of marine reserves adaptive management, Senate Bill 1510 (2012) required an assessment and report on the Oregon Marine Reserves Program due to the Oregon Legislature in early 2023. The assessment serves as a check-in on the program and implementation of the marine reserve mandates. The bill stipulated the Oregon Scientific and Technical Advisory

Committee (STAC)[4] was to select a university team, based at an Oregon public university, to research and prepare the report for the Legislature. The report was to include:

- An assessment of social, economic and environmental factors related to the reserves and protected areas; and
- Recommendations for administrative actions and legislative proposals related to the reserves and protected areas; and
- Any other scientifically based information related to the reserves and protected areas that the public university described in this subsection deems relevant or material.

STAC developed an evaluation framework and criteria to guide the assessment and issued a Request for Proposals in 2021, to solicit a team of university researchers. To further aid the assessment, ODFW produced the *Marine Reserves Program Synthesis Report: 2009-2021* (ODFW 2022), providing a comprehensive overview of the ODFW program and first 10 years of marine reserves implementation. The ODFW Synthesis Report was provided to the university team in January 2022. The University Assessment Report (Hopf et al. 2022a) was then delivered to the Oregon Legislature in February of 2023.

This decadal program assessment has provided many insights into successes, challenges, and areas for improvement as the program now begins to move into the next phase of long-term human dimensions and ecological monitoring, program implementation, and adaptive management.

Background: ODFW's Human Dimensions Research Program

What Is Human Dimensions Research?

Human dimensions research looks at the different ways humans use, experience, value, and depend on the natural environment. This research is interdisciplinary and draws upon multiple social science disciplines. The ODFW Marine Reserves Program created a long-term human dimensions research program in order to study the social and economic impacts of Oregon's marine reserves, as mandated by the Oregon Legislature.

> When conservation strategies such as marine reserves are introduced, they can create positive changes – such as increased tourism dollars to small businesses; negative changes – such as increased feelings of distrust towards government or loss of income to fishers; or no changes.

What Has ODFW's Research Focused On?

The marine reserve goals and objectives pertinent to human dimensions research provide that Oregon's reserves are to **avoid significant adverse social and economic impacts on ocean users and coastal communities** and that research and monitoring information is to be used to **support nearshore management** and the adaptive management of marine reserves (OPAC 2008).

[4] The Oregon Scientific and Technical Advisory Committee (STAC) is a legislatively mandated body (ORS 196.451) that provides scientific and technical advice and recommendations to OPAC and state agencies on matters related to ocean and nearshore resources.

Further, implementation principles and guidelines provide that **positive social and economic impacts** will be sought (OPAC 2008).

During the first 10 years of marine reserves implementation, ODFW's research has focused on understanding and describing the different ways that regions, communities, social groups, and individuals are affected by Oregon's marine reserves. The research was designed to look at possible social, economic, and cultural impacts to understand who is being impacted and how.

Research Program Resources And Approach

Assessing the socioeconomic impacts of Oregon's marine reserves has required a broad-based interdisciplinary research approach. To do this ODFW has worked with academic and private consultant research partners, using various research methods, across multiple social science disciplines – including fisheries economics, rural and natural resource sociology, social psychology, and anthropology.

ODFW Staff And Budget

ODFW's research program includes one full-time, permanent staff position dedicated to human dimensions research. The position is filled by a social scientist with expertise and experience in the human dimensions of natural resources (e.g. PhD level with more than a decade of experience in applied human dimensions research). In addition to one staff, the program has a modest research budget that has ranged between USD$85,000-$126,000 per biennium to support human dimensions research projects. The majority of the research budget goes towards contracts with external collaborative research partners.

The ODFW staff conducts several internal research projects and serves as the lead research coordinator and contract manager for all external research projects. A significant portion of staff time in the first 10 years was spent identifying, connecting, and cultivating relationships with external social scientists.

Collaborative Research Projects And Contracts With Partners

With the exception of several internal research projects, ODFW depends on partners to carry out most of the human dimensions research. Research projects are designed in collaboration between ODFW and partners, and are led by the partner. ODFW provides state funds for research projects through contracts or Inter-Governmental Agreements (IGAs). Partners contribute specialized expertise and often additional staff, funding, volunteers, and/or equipment to the project. All projects must follow state contracting policies and procedures to receive any state funds provided by ODFW.

Given the very modest ODFW research budget and because much of the research being implemented was considered novel, both for the state of Oregon and for MPA monitoring, ODFW often provided seed money and in-kind staff time for projects and partners were able to secure grants to fund the remainder of the projects. Grant funds often matched ODFW's research budget each biennium.

To help foster collaborative projects with universities, ODFW formalized partnerships with some academic institutions. Examples included establishment of a long-term (e.g. 10 year) IGA or agency staff having courtesy faculty appointments. These arrangements help cultivate ongoing relationships between academic and ODFW researchers, providing continuity across numerous projects and facilitating engagement with graduate students. These arrangements have also helped streamline administrative procedures allowing ODFW to provide state funds to support research, support post-graduate fellows, and the sharing of resources between the agency and universities.

What Oregon Did: Human Dimensions Research

Early Stages: Research Planning

Workshop

In 2008, a technical workshop was organized by STAC to review a range of economic research topics relevant to the marine reserves. The workshop report (Hannah and Sampson 2009) was used to help inform ODFW on the development of a human dimensions research program and long-term monitoring plan.

Monitoring Plan Development

From 2010 to 2012, ODFW worked with STAC and additional economics and social science experts to devise the *Marine Reserves Human Dimensions Monitoring Plan* (ODFW 2012, updated 2017) to guide the long-term human dimensions monitoring and research of Oregon's reserves. The plan outlines the monitoring design, research questions, and monitoring activities for human dimensions research and notes existing complementary research. The monitoring plan is scheduled to be reviewed and updated every five years, in consultation with STAC.

Team Of Science Advisors

ODFW also devised an informal, expanded team of technical advisors to help refine the research agenda over the ensuing years. This informal team met annually to share updates on current marine reserve related research, discuss research gaps, and discuss potential future collaborations. The annual meeting also served as an important forum for building a community of social scientists engaged in human dimensions of natural resources work in Oregon.

Research Design

The first ten years of human dimensions research focused on collecting data to assess the social, cultural, and economic impacts from implementation of the marine reserves on Oregon regions, communities, social groups, and individuals and to study what changes may have occurred over time since their designation. This section provides a brief discussion of the human dimensions research program design as implemented by ODFW. Table 8 provides an overview of the program research design.

Table 8: Overview of Human Dimensions Research Program Design

Types of Impacts Social Economic Cultural **Impacts On** Regions Communities Social groups Individuals	**Research Questions** 1. Are people knowledgeable about the marine reserves? 2. What are the public's attitudes about the marine reserves? 3. What are the economic impacts of the marine reserves on fishermen? 4. What are other significant economic impacts of the marine reserves on local communities? 5. What are the social impacts of the marine reserves? **Broader Research Questions** 1. How do social and cultural values shape the way communities manage and relate to the ocean? 2. How do coastal communities adapt to social, political, or ecological change? 3. Under what circumstances is it possible for different stakeholder groups to come together and make difficult decisions about ocean management? 4. How do we build community resilience to risk? **Four Areas of Research Focus** 1. Social and Economic Characterizations of Communities 2. Direct Uses of Coastal and Marine Reserve Areas a. Fisheries b. Recreation and Aesthetic Engagement 3. Attitudes and Perceptions of Implementation and Management 4. Assessment of Social and Environmental (Non-Market) Values	**Complementary Interdisciplinary Research** ● Fisheries economics ● Rural and natural resource sociology ● Social psychology ● Anthropology ● Political science **Tools and Methods** ● Surveys (mixed methods surveys, intercept surveys, participatory GIS surveys) ● Pressure counts (observational surveys) ● Economic modeling and related data aggregation ● Community studies (ethnographies, community case studies) ● Analyses of secondary data (time series analyses) ● Individual interviews **Types of Data** ● Quantitative ● Qualitative ● Primary data ● Secondary data **Data Analyses** ● Regional economic impact (REI) ● Time series ● Difference-in-differences (DID) ● Synthetic control ● Comparative ● Qualitative **Multiple-lines of Evidence Across Studies**

Research Questions

Based on the OPAC policy recommendations, the following research questions were developed by ODFW in consultation with STAC and additional experts.

1. Are people knowledgeable about the marine reserves?
2. What are the public's attitudes about the marine reserves?
3. What are the economic impacts of the marine reserves on fishermen?
4. What are other significant economic impacts of the marine reserves on local communities?
5. What are the social impacts of the marine reserves?

Additionally, do these change over time and are long-term impacts different from short-term or initial impacts?

ODFW also developed a set of broader research questions aimed at increasing knowledge and understanding of social relationships that can be used to support nearshore resource management and policy in the future.

1. How do social and cultural values shape the way communities manage and relate to the ocean?
2. How do coastal communities adapt to social, political, or ecological change?
3. Under what circumstances is it possible for different stakeholder groups to come together and make difficult decisions about ocean management?
4. How do we build community resilience to risk?

Focus Research In Four Areas

The monitoring plans identified, and research projects were developed around, four areas of research:

1. Social and Economic Characterizations of Communities. Collect 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 on the coast and in proximity to marine reserve sites. Conduct subsequent community studies and use related secondary data to provide information that can be used to assess trends in social welfare and economic conditions of coastal communities.

2. Direct Uses of Coastal and Marine Reserve Areas.

<u>Fisheries</u>**:** Conduct studies and use secondary data that allow assessment of trends over time among commercial, charter, and recreational fisheries related to the marine reserves. Identify physical areas of use and which fisheries were conducted in the areas. Identify

which and how communities and individuals may be affected from displacement or disruption of these activities.
Recreation and Aesthetic Engagement: Studies to understand other types of recreational use and aesthetic engagement with the coast. Understand what uses presently exist and monitor changes that may occur with implementation of the marine reserve sites. Collect social and economic data from users of the areas.

3. **Attitudes and Perceptions of Implementation and Management.** Studies to advance understanding of the knowledge, attitudes, and perceptions of residents of communities of place (geographic coastal communities), communities of interest (stakeholders), and the general public (Oregon residents) toward marine reserves and management. Subsequent iterations of studies should allow for comparisons with earlier baseline data.

4. **Assessment of Social and Environmental (Non-Market) Values.** Studies to advance the understanding of how Oregon residents value the ocean and the marine reserve sites. Research that examines the values associated with the natural resources and ecological characteristics of these areas. How values may be different across stakeholders, communities, and among the general public.

Complementary Interdisciplinary Research Projects - Multiple Lines Of Evidence

To address the research questions and cover the four areas of research mentioned above, ODFW and partners set out to employ a range of social science research methods and tools, across multiple social science disciplines. Different social science disciplines can provide different tools to address the same research question. These diverse threads of disciplinary evidence can then be compared and either corroborate or challenge the conclusions drawn from another line of inquiry. To date, ODFW and partners have conducted 17 research projects (Table 9). ODFW keeps a master list of all human dimensions research projects, with links to reports and publications from each project, on the "Resource Library" page of their website oregonmarinereserves.com.

Table 9: List of Human Dimensions Research Projects Conducted by ODFW and Partners Between 2010-2021, Arranged by Research Focus Area

1. **CHARACTERIZATIONS OF COMMUNITIES**
   A. Coastal Community Profiles - Fishing Occupational Profiles
   B. Coastal Community Profiles - Background Information (using secondary data)
   C. Coastal Community Profiles - Community Resilience, Adaptation, and Communication

2. **DIRECT USES OF COASTAL ENVIRONMENTS**
   Fishing, Recreation, and Aesthetic Engagement
   A. Modeling the Economic Impacts of Fishing Restrictions
   B. Visitor Counts and Surveys
   C. Ocean Awareness Visitor Survey

D. Fishing Effort Shift - Fishermen Interviews and Direct Observations

E. Fishing Effort Shift - Survey

F. Recreational Fisher Survey: Knowledge, Attitudes, Perceptions, and Impacts to Participation

G. Economic Impact from Research Activities

H. Coastal Communities: Difference-in-Differences and Synthetic Control Approach to Detecting Socioeconomic Impacts

3. ATTITUDES AND PERCEPTIONS OF IMPLEMENTATION & MANAGEMENT

A. Oregon Residents' Attitudes and Perceptions Surveys

B. Coastal Community Resilience and Subjective Wellbeing

C. Fishing Community Resilience Related to Marine Reserve Implementation

D. Business Surveys

4. SOCIAL AND ENVIRONMENTAL (NON-MARKET) VALUES

A. Oregonian's Perspectives on Marine Conservation: Statewide Survey of Social Values, Attitudes, and Opinions

B. Resident's Perceived Values of Ecosystem Services

View ODFW's Master List of all human dimensions research projects, with links to reports and publications.

The following sections highlight research tools and methods, types of data, and types of analyses used in the various human dimensions research projects.

Research Tools and Methods

The following social science research tools and methods have been used by ODFW and partners:

1. Surveys (mixed methods surveys, intercept surveys, participatory GIS surveys)
2. Pressure counts (observational surveys)
3. Economic modeling and related data aggregation
4. Community studies (ethnographies, community case studies)
5. Analyses of secondary data (time series analyses)
6. Individual interviews

Quantitative and Qualitative Data

Some research projects provide quantitative information, while others provide qualitative or descriptive information. Qualitative data are often able to provide additional context to quantitative findings or can drill down and uncover impacts that would not have otherwise been detected in quantitative studies, such as impacts on individuals or some of the social impacts that result from MPA implementation.

Primary and Secondary Data

Many studies collect and use primary data, generally survey data or interviews collected by ODFW staff or research partners. These data are collected directly from participants (i.e. research subjects) either from random samples (mail, mixed mode, internet, and intercept surveys) or from volunteer individuals using qualitative methods such as snowball sampling (semi-structured qualitative interviews of individuals) or, in a few instances, requests for volunteers (a participatory GIS survey, some interview protocols). Other studies, such as economic models and time series analyses, are based on preexisting secondary data (e.g. fisheries landings data or U.S. Census data) (Swearingen and Fox 2022).

Data Analyses

Types of data analyses used include regional economic impact (REI), time series, difference-in-differences (DID), synthetic control, comparative, and qualitative analyses.

Data Collection

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 (Swearingen and Fox 2022).

Some data were continuous data streams, such as secondary demographic and economic data (e.g., fisheries landings, U.S. Census data). Many research studies were a series of discrete research projects, such as visitor intercept surveys, repeated over time. Other studies collected one-time qualitative data such as ethnographic community studies (Swearingen and Fox 2022).

Key Indicators

Oregon’s goals and objectives state that the reserves are to avoid **significant adverse** social and economic impacts on ocean users and coastal communities. The principles and guidelines further provide that **positive** social and economic impacts will be sought. In this context, determination of what constitutes “significant” is a policy decision, not a scientific research decision. “Significant” was not defined by either OPAC or the Oregon Legislature. Furthermore, tradeoffs are common in natural resource policy decisions and whether the resulting impacts are perceived as “adverse” or “positive" often depends on the perspectives of the parties involved. Finally, the mandate to assess the socioeconomic impacts of the marine reserves was exceptionally broad.

Given these challenges, ODFW made the decision that instead of selecting key 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.

Moving Forward: Development Of Key Indicators

After 10 years of research there is now a baseline understanding of who is being affected by the marine reserves and how. The University Assessment Report (Hopf et al. 2022a) recommended that, moving forward, ODFW delineate a collaborative process through which social monitoring data can be interpreted to affect policy decisions (i.e. what constitutes "significant" and "adverse"). It also recommends the collaborative process be used to clarify who the state of Oregon is concerned with impacting and in what ways. This will then be used by ODFW to develop an adaptive management plan that includes identification of consistent measurable indicators of social impacts.

Data Management

In most instances, each Principle Investigator kept and managed the data from the research project they were leading. Much of this research involves human subjects and university researchers must have their research pre-approved by their Institutional Review Board (IRB), an administrative body established to help to protect the rights and welfare of human research participants. There are often strict confidentiality rules around human subjects data. In addition, much of the fisheries data used come from ODFW fisheries management programs or the U.S. federal government and have strict confidentiality rules and terms of use. Formal data requests may be made to ODFW, for those data associated with ODFW led research projects and data agreements

Data Analysis And Synthesis

Individual Projects

At the end of each research project or project phase (for studies repeated over time) data were analyzed and a project report was developed and provided to ODFW. All reports were reviewed and approved by ODFW before being finalized.

Synthesis

Although the human dimensions monitoring plan (ODFW 2012, updated 2017) defined the research questions that drove human dimensions data collection, there were no details about how those data would be used during the program assessment process. Most of the data collected using the various disciplines and research tools would be compared over time, with baseline data compared to the most recent data available leading up to the Synthesis Report (ODFW 2022). Some data were continuous data streams, such as secondary demographic and economic data (e.g., fisheries data, Census data). Time series analyses were used for comparisons across these types of data. Many of the research studies were a series of discrete research projects, such as visitor intercept surveys repeated over time. Other studies were based on qualitative data. (Swearingen and Fox 2022).

Units of Analysis: From Impacts at the State Level to Impacts on Individuals. In 2017, in advanced preparation for the Synthesis Report, ODFW began consultation with STAC on how best to organize and synthesize the human dimensions research analyses. As the human dimensions research was intended to describe the different ways that regions, communities, social groups, and individuals are impacted by Oregon's reserves, it was decided that analyses should be performed and impacts reported at the following scales (i.e. units of analysis) organized from largest (e.g., state, region) to successively smaller units of analysis (e.g., port groups and counties, geographic communities, stakeholder groups, personal interviews). Multiple different studies and disciplines might contribute insight into understanding reserve impacts at any given unit of analysis. By comparing these diverse threads of disciplinary evidence, they could corroborate or challenge the conclusions drawn from another line of inquiry (Swearingen and Fox 2022).

Units of analysis, from largest to smallest:

- State Level
- Coast Region
- Coastal Communities
- Communities of Interest
- Fishing Occupational Community
- Individuals

The analyses and synthesis of the human dimensions research are provided in the Human Dimensions Research Technical Appendix (Swearingen and Fox 2022) of the Synthesis Report.

Pathways To Decision Making Moving Forward

The following recommendations were made in the University Assessment Report (Hopf et al. 2022a) pertaining to human dimensions research, socioeconomic impacts, and decision making moving into the next phase of marine reserves implementation in Oregon.

- ODFW should delineate a collaborative process through which social monitoring data can be interpreted to affect policy decisions. Include steps for decision making, conflict management, and clarity on who the state of Oregon is concerned with impacting and in what ways. Suggest that the U.S. Magnuson-Stevens Fishery Conservation and Management Act (Public Law 94-265) could provide an example for defining such a process.

- ODFW should develop an adaptive management plan that includes clear objectives, defined decision-making criteria and timelines, and stakeholder engagement processes. The plan should include:
    - Specific, measurable, achievable, relevant, and time-oriented objectives for socioeconomic monitoring and research.
    - Consistent measurable indicators of social impacts.

Communications And Reporting

Science communications has been a critical component of the ODFW Marine Reserves Program providing transparency and helping build trust with constituents. Communications objectives include building 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.

ODFW provides research findings in infographics, reports, and publications on the “Resource Library” page of their website oregonmarinereserves.com. They also highlight research findings and stories in their monthly electronic newsletter and on the “Reserves News” page of their website. ODFW commits to producing technical research reports or scientific journal publications at least every two years.

Beyond producing journal publications and individual research project reports, ODFW struggled with human dimensions science communications and endured mounting criticism from constituents and STAC. In 2018, ODFW contracted two social scientists to assist them in developing a human dimensions research communications strategy. By ODFW reframing what human dimensions research is and how to communicate research findings (i.e. rolling-up findings across projects based on each research question instead of presenting findings for individual research projects or trying to explain how all the various research projects fit together), along with a concerted effort to produce more human dimensions research outreach products, significantly improved trust with constituents and STAC. An overview of the communications strategy and an example slide deck presentation are provided here.

Examples and links to human dimensions outreach materials, reports, and publications:

- Infographics
- “Reserves News” posts
- Master list of all human dimensions research projects, with links to reports and publications
- Human Dimensions Research Technical Appendix (Swearingen and Fox 2022) of the Synthesis Report

Case Study 3:

United Kingdom Marine Monitoring and Assessment Strategy

Nudibranch, Credit: Joint Nature Conservation Committee/Marine Scotland Science

Key Lessons from this Case Study

Regular Reporting Mandates Support Assessments and Adaptive Management
National government 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 on measures that are used to maintain or improve the conditions of the marine environment. Collectively these requirements support adaptive management by ensuring that data are collected and made available to managers and stakeholders for decision-making and public consultations.

Take Stock of Existing Monitoring Programs and Data
A strength of the UK Marine Strategy is its emphasis on identifying and leveraging existing datasets and monitoring programs to assess key indicators, including fish and cetaceans, to realize efficiencies and make targeted investments to improve monitoring programs and address data gaps.

Align Marine Monitoring with Other Monitoring Requirements
In addition to taking stock of existing data sets and monitoring programs, there are opportunities to realize synergies in monitoring by ensuring and alignment of marine monitoring with other national monitoring requirements. In particular, the UK marine strategy was explicitly designed to ensure that descriptors and methods are aligned with OSPAR Conventions (Oslo and Paris Conventions) and the Water Framework Directive.

Leverage New Technologies
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 deploying SmartBuoys, benthic landers, and remote sensing platforms to monitor eutrophication and related indicators. Over time these approaches may improve or potentially replace more costly and time-intensive monitoring approaches.

Engage Stakeholders in Citizen Science
Monitoring of beach litter as part of the UK Marine Strategy is undertaken by volunteers and environmental organizations, providing an important opportunity for raising awareness about the Marine Strategy and environmental issues, sharing knowledge, and contributing to broader social and environmental objectives.

Introduction

The United Kingdom's (UK) marine monitoring and assessment strategy (Marine Strategy) provides a general framework for planning and monitoring the impacts of marine policies across the UK, including MPAs (DEFRA 2019). The marine strategy was first released in 2012 and updated in 2018 as part of a six-year reporting and revision cycle and is organized into three parts. Part 1 identifies targets and indicators of Good Environmental Status, including an initial assessment of progress and outcomes between 2012 and 2018. Part 2 describes monitoring programs and approaches for measuring Good Environmental Status (GES), while Part 3 describes measures that have and/or will be used to achieve GES. GES is defined as the environmental status of marine waters where they constitute ecologically diverse and dynamic ocean and seas that are clean, healthy, and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations (UK Marine Strategy, Part 2, page 7). While the Marine Strategy itself is broader than MPANs, it offers important lessons for developing indicators and designing systems for regional-scale monitoring of marine systems.

Background: UK MPAN

United Kingdom's Marine Reserve System

The UK MPAN was established and guided by the UK Marine and Coastal Access Act (2009) which compels the development of an ecologically-coherent and well-managed MPAN to complement and build upon existing MPAs and is supported by additional legislation from the devolved administrations of the UK (i.e., England, Scotland, Wales and Northern Ireland) and international agreements. The MPAN now includes over 378 MPAs covering an area of approximately 338,545 square kilometers or 38% of UK waters (JNCC 2022). The MPAN in the UK includes marine areas that have been designated for the purpose of conservation and protection of marine biodiversity, habitats and species and includes a range of different designations, including:

1. Marine Conservation Zones (MCZs), which are areas designated by the UK government specifically for the protection of nationally important marine wildlife, habitats, and geology;
2. Special Areas of Conservation (SACs), which were designated to protect Europe's most threatened species and habitats under the EU Habitats Directive and are now implemented through changes to the Habitats Regulations;
3. Special Protection Areas (SPAs), which were designated to protect bird species of European importance and migratory bird species and their habitats and are now implemented through changes to the Habitats Regulations;
4. Nature Conservation MPAs, which are areas designated by the devolved governments of Scotland (Marine (Scotland) Act 2010), Wales, and Northern Ireland (Marine Act (Northern Ireland) 2013) for the protection of marine wildlife and habitats;
5. Sites of Special Scientific Interest (SSSIs) / Areas of Special Scientific Interest (ASSIs) – which are designated to protect any area of special interest on the basis of its flora, fauna, or geology under the Wildlife and Countryside Act;
6. Ramsar Sites, which are wetlands of international importance designated under the Ramsar Convention covering coastal and terrestrial, including some marine features.

The specific process of developing and managing the MPAN has varied between England, Scotland, Wales, and Northern Ireland, while adhering to the following five principles (Chaniotis et al. 2018):

1. Features: the network should represent the range of habitats and species for which MPAs are considered appropriate – with a greater proportion of particularly threatened and/or declining features.
2. Representativity: the network should include areas that best represent the range of habitats and species.
3. Connectivity: the network should comprise MPAs that are well-distributed and take into account linkages between marine systems.
4. Resilience: the network should include more than one example of a feature in individual MPAs and ensure they are of sufficient size to deliver conservation benefits.
5. Management: the network should ensure the protection of marine habitats and species for which an MPA has been identified.

Goals of the UK Marine Strategy

The UK Marine Strategy is designed to contribute to 'clean, healthy, safe, productive and biologically diverse ocean and seas' and allow it to fulfill international commitments and reporting obligations related to the UN Convention on the Law of the Sea (UNCLOS), the UN Sustainable Development Goals (Goal 14), the OSPAR North-East Atlantic Environment Strategy, and the Convention on Biological Diversity. It does so by seeking to achieve Good Environmental Status (Marine Strategy, Part One).

Legislation and Policy Guidance

The UK MPAN was established by the Marine and Coastal Access Act in 2009, and guided by several pieces of international, UK-level, and country level legislation. The Marine and Coastal Access Act includes provisions for the establishment of Marine Conservation Zones and Marine Nature Reserves in England, Wales, and Northern Ireland, while the Marine (Scotland) Act allows for the establishment of Nature Conservation. Sites of Special Scientific Interest can be designated through the Wildlife and Countryside Act (1981). Monitoring and assessment of UK marine areas are guided by the Marine Strategy Regulations (2010) which requires an assessment of progress towards the objectives of the UK Marine Strategy to be developed and shared every six years.

UK's Marine Monitoring and Assessment Strategy

The UK's Marine Monitoring and Assessment Strategy is organized around the assessment of 11 high-level descriptors of Good Environmental Status (GES) as outlined in Figure 7. Each descriptor is assessed on a three-point scale that indicates whether GES has been achieved, partially achieved, or not achieved, and whether trends are stable, improving, or declining, based upon a set of underlying indicators or assessments. For instance, the most recent assessment suggests that GES for seals has been partially achieved and improving since 2012 based upon an increase in abundance and a healthy population of harbour seals in West

Scotland, but poorer overall conditions in the Greater North Sea. The 11 descriptors included within the UK's Marine Strategy are aligned with those of the European Union's Marine Strategy and Framework Directive (2008) to support monitoring requirements prior to Brexit and coordinate monitoring activities and reporting with other contracting parties to the OSPAR Convention. The following subsections provide a brief overview of the underlying indicators for each descriptor and methods used to assess them. **The value of this approach for other MPAs and MPANs is that it show how indicators can be connected to management goals with clear targets that the indicators are then measured against, and can be used to inform decision making**. This approach can also help integrate MPAN monitoring with broader ecosystem-based management goals.

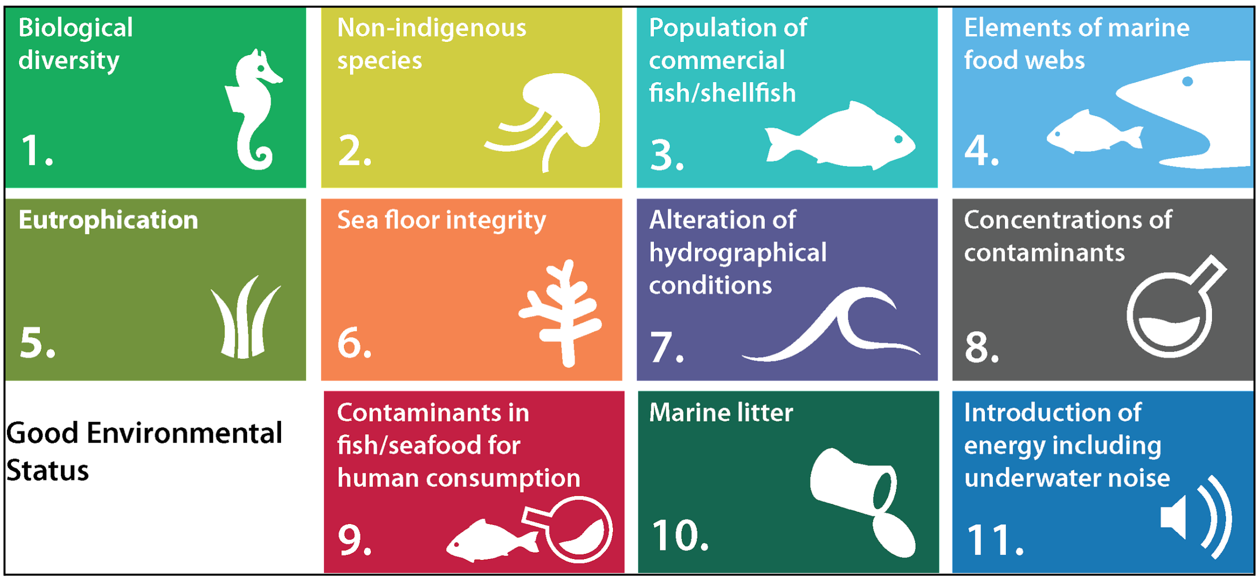


Figure 7: Descriptors of Good Environmental Status (as presented in Directive 2008/56/EC of the European Parliament and the Council).

Biological Diversity: Cetaceans

Three core indicators assess the status of cetaceans in the UK: 1) the abundance and distribution of coastal bottlenose dolphins, 2) the abundance and distribution of other cetaceans, and 3) marine mammal bycatch as outlined in Table 10. The abundance of coastal bottlenose dolphins is assessed across 4 different assessment units using photo-identification, line transects and sight-re-sight methods. The abundance of other cetaceans, including harbour porpoise, offshore bottlenose dolphins, minke whale, fin whale, and sperm whale, are assessed using primarily aerial and some shipboard surveys, and modelled using a point (or track line) independence model. Although there have been several survey programs operating in the region over the last thirty years, only one species (Minke whale) satisfies the requirement of having at least 3 abundance estimates in a 10 year period. As a result, the UK Monitoring and Assessment Reporting Group (MARG) is considering increasing the frequency of SCANS surveys. Finally, cetacean bycatch aims to achieve a target of less than 1.7% mortality from all anthropogenic sources, and less than 1% mortality from bycatch, and is assessed by combining data on cetacean bycatch from observer programs, fishing effort, and abundance estimates.

Bycatch estimates are generated for two of the most common bycatch species, harbour porpoise and common dolphin.

Table 10: Cetacean indicators, targets and monitoring programs

Indicator	Target	Monitoring Programs and Methods
Abundance and distribution of coastal bottlenose dolphins	No decrease of greater than 5% over a ten-year period	Bottlenose dolphin inshore population monitoring • Photo identification • Line transects • Capture-recapture At least 4 abundance estimates across different years in a 10 year period are required
Abundance and distribution of other cetaceans	No decrease of greater than 5% over a ten-year period • Species covered include harbour porpoise, offshore bottlenose dolphin, short-beaked common dolphin, striped dolphin, white-beaked dolphin, minke whale. fin whale, long-finned pilot whale. beaked whale and sperm whale	Small Cetaceans in European Atlantic waters and the North Sea (SCANS) surveys; CODA (Cetacean Offshore Distribution and Abundance in the European Atlantic; North Atlantic Sightings Surveys (NASS); Norwegian Independent Line Transect Surveys (NILS) for minke whales. • Aerial or shipboard surveys • Abundance estimates generated using the point (or track line) independence model At least 3 abundance estimates across different years in a 10 year period are required
Cetacean bycatch	Total anthropogenic mortality is less than 1.7% of the best available estimate of abundance for Bycatch is less than 1% of the best available abundance estimate • Species covered include harbour porpoise and common dolphin	UK Bycatch Monitoring Programme (BMP) ; Cetacean Strandings Investigation Programme (CSIP) and Scottish Marine Animal Strandings Scheme (SMASS) • Bycatch estimated based on observer data and fishing effort • Abundance based on surveys above

Biological Diversity: Seals

The status of seals in the UK are assessed on the basis of two sets of indicators, namely: 1) the abundance and distribution of grey seals and harbour seals, and 2) grey seal pup production as outlined in Table 11. Data are collected as part of a long-term seal population monitoring program that combines aerial surveys and ground-based counts to estimate the total size of the population during moulting or breeding, and grey seal pup production. Grey seal pup production is estimated using a statistical model for each colony based on counts. In both cases, targets are set based on a decline of no more than 1% per year over a six-year period, or no more than 25% from the baseline year (1992 or the first year in which information is available). Although the program records presence at haul-out and breeding sites to provide insights about distribution, the monitoring program is not specifically designed to provide estimates and track trends related to the distribution of seals.

Table 11: Seal indicators, targets and monitoring programs

Indicator	Targets	Monitoring Programs and Methods
Seal abundance and distribution	Seal abundance decline of less than 1% per year over a six-year period Seal abundance decline of less than 25% from baseline year. Presence at haul-out and breeding sites (no specific target) ● Species covered include grey seal and harbour seal	Seal Population Monitoring Program ● Land based counts during moulting (harbour seal) or breeding (grey seal) ● Total abundance of grey seals is modelled using summer counts of grey seals and counts of pups in autumn and winter
Grey seal pup production	Grey seal pup production decline of less than 1% per year over a six-year period Grey seal pup production decline of less than 25% from baseline year.	Seal Population Monitoring Program ● Aerial surveys ● Ground or boat-based counts ● Estimates of total pup production are modelled for each colony

Biological Diversity: Birds

GES of birds for the UK marine strategy is assessed across several different indicators, including breeding success or failure of over 20 seabird species (with particular emphasis on Kittiwake, the presence of invasive mammals on offshore islands, and their distribution and abundance. Monitoring is undertaken as part of the Seabird Monitoring Programme of the UK and Ireland (BTO 2023). It monitors seabirds throughout the UK every year. Breeding seabirds and their nests are monitored on land during the breeding season, while a variety of methods are used to monitor non-breeding waterbirds as they migrate or overwinter along the coast of the UK. In general, assessments of breeding seabirds are based upon a time series of sampled colonies, with missing annual observation estimated using a generalized linear model. Notably, targets for Kittiwake breeding success are explicitly designed to isolate management effects by accounting for the impacts of climate change. More specifically, Kittiwake breeding success is strongly influenced by local mean sea-surface temperature in February and March of the previous year, and as such targets are based on alignment between breeding success and a modelled baseline (Figure 8).

Table 12: Birds indicators, targets and monitoring programs

Indicator	Targets	Monitoring Programs and Methods
Kittiwake breeding success	Number of chicks fledged per pair is not significantly different, statistically, from levels expected under prevailing climatic conditions such as sea surface temperature.	Seabird Monitoring Programme of the UK and Ireland; Sea Surface Temperature datasets ● Count of fledged chicks per colony ● Missing years are estimated by statistical models ● Baseline is estimated using a statistical model sea surface temperature
Breeding success / failure	Less than 5% (or 15 year mean for terns) of colonies experiencing breeding failure ● Breeding failure is defined as annual mean breeding success of less than 0.1 chicks per pair ● Covers over 20 species	Seabird Monitoring Programme of the UK, Ireland and European partners ● Count of fledged chicks per colony ● Missing years are estimated by statistical models
Invasive mammals	Reduction in risk to island seabird colonies from non-native mammals, based on: ● Presence/absence of invasive mammals on offshore islands ● Risk assessment based on monitoring, quarantine measures and rapid response	UK invasive predatory mammal surveillance under the Biosecurity for LIFE project(pilot) ● Measuring presence/absence of invasive mammals on offshore islands ● Risk assessment based on scoring through interviews of site managers
Distribution	No major shifts or shrinkage in the population distribution of marine birds in 75% of species monitored ● Changes in occupancy ● Shift index which measures the extent to which a species has shifted from one area to another ● Covers 10 species	Seabird Monitoring Programme (SMP); Wetland Bird Survey (WeBS); Periodic bird surveys; Breeding Atlas; Non-Estuarine Waterbird Survey ● Measure presence/absence of birds in 2km by 2km grids and compares over 2-time periods
Abundance	Changes in abundance of marine birds should be within individual target levels in 75% of species monitored. Species-specific thresholds are used ● 0.8 of baseline (1992) for species that lay one egg ● 0.7 of baseline (1992) for species that lay more than 1 egg ● Includes 127 indicators that distinguishes between	Seabird Monitoring Programme (SMP); Wetland Bird Survey (WeBS); Periodic bird surveys; Breeding Atlas; Non-Estuarine Waterbird Survey; Data from OSPAR contracting parties ● Missing data was estimated using statistical models ● Count of breeding pairs or adults per species per colony per year for breeding bird species ● Numbers of birds, per species, per site, and per year that are counted from the

	species, location and breeding/non-breeding abundance	land or the air for non-breeding bird species

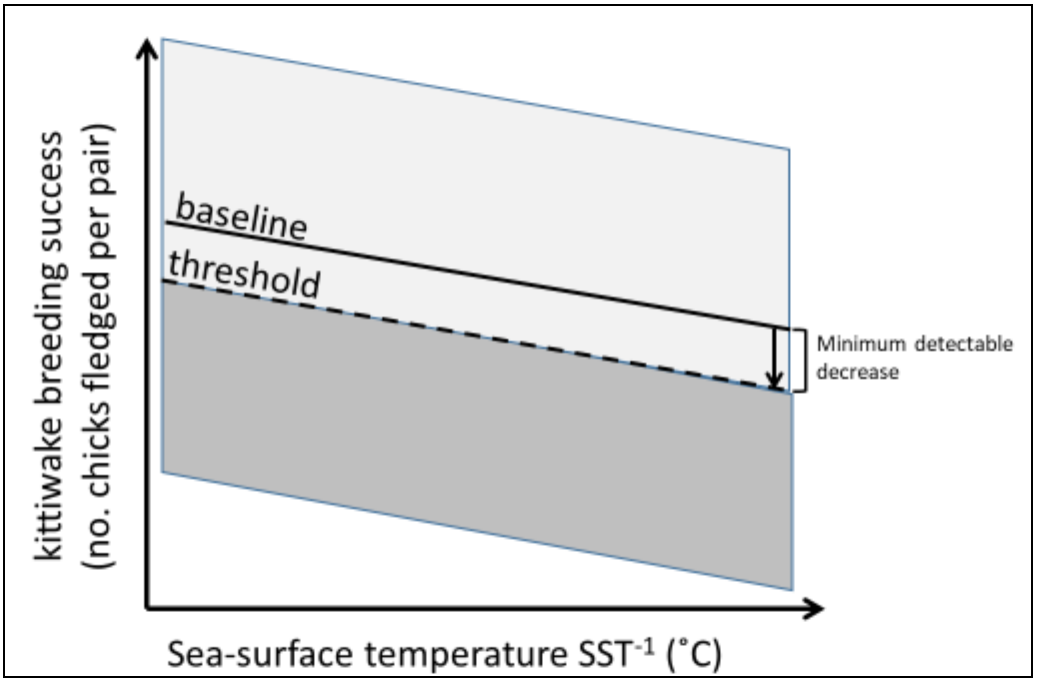


Figure 8: Comparing breeding success to baseline (Source: https://moat.cefas.co.uk/biodiversity-food-webs-and-marine-protected-areas/birds/kittiwake-breeding-success/)

Biological Diversity: Fish

The status of fish across areas covered by the UK marine strategy is assessed across several different indicators, including abundance of sensitive species, size composition and a large fish index using data collected through otter and beam trawl scientific surveys. ICES international bottom trawl survey is particularly important and provides data on the distribution, abundance, and size composition of fish and other organisms living on or near the sea bottom in the Northeast Atlantic Ocean (DATRAS 2023). The survey is conducted annually in the late summer and early autumn and involves the use of standardized bottom trawl nets towed behind research vessels. The nets are designed to sample the seafloor at a fixed depth, and the catch is sorted, identified, and weighed to determine the abundance and size distribution of different species.

Table 13: Fish indicators, targets and monitoring programs

Indicator	Targets	Monitoring Programs and Methods
Size composition	No change in the size composition of fish communities based on trends with respect to typical length. • Indicator has 4 values (long term decrease to a minimum state, long term decrease, long-term increase or no change) • Distinguishes between pelagic and demersal communities and region	Scientific fisheries surveys using otter trawl and beam trawl, including the International Bottom Trawl Survey programme • Indicator is aggregated at the survey level. • Trends are modelled using locally weighted scatterplot and breakpoint analyses were used to identify changes.
Large fish index	Size-composition of fish communities should reflect a healthy status and no change in the size composition of fish communities based on large fish index (LFI) • LFI measures proportion of large fish in a survey, where large fish are defined for each survey and exclude certain species or types thereof	Scientific fisheries surveys using otter trawl and beam trawl, including the International Bottom Trawl Survey programme • Indicator is aggregated at the survey level. • Assessment thresholds were set using a variety of methods, including 3 X lowest five year moving average, reference values, long-term correlations or trend-based analysis
Community	No change in the size composition of fish communities based on trends in mean maximum length • Indicator has 4 values (long term decrease to a minimum state, long term decrease, long-term increase or no change) • Distinguishes between pelagic and demersal communities and between the Greater North and Celtic Seas	Scientific fisheries surveys using otter trawl and beam trawl, including the International Bottom Trawl Survey programme • Indicator is aggregated at the survey level. • Trends are modelled using locally weighted scatterplot and breakpoint analyses were used to identify changes.
Abundance	Increasing abundance of “sensitive species” and if that fails no further population decline • Sensitivity defined in terms of the average life-history trait metric or the proportion failing to spawn metric	Scientific fisheries surveys using otter trawl and beam trawl, including the International Bottom Trawl Survey programme • Species-survey level indicators based on position (i.e., quartile) of abundance estimate • Survey level indicator based on number of species recovering or with no further decline

Indicator	Targets	Monitoring Programs and Methods
	● Recovery defined abundance in the top 25% of a time series ● No further population decline defined as abundance above the lowest 25% of a time series ● Indicators are available at the species-survey, survey and integrated level	● Integrated assessment uses probabilistic and averaging methods. ● Averaging method calculated species abundance as a fraction of species assessment thresholds (i.e, 75% or 25%) with values above one indicating acceptable status.

Pelagic Habitats

The UK marine strategy monitors the conditions of pelagic habitats on the basis of two sets of indicators, plankton biomass and plankton communities. Data are collected from up to 11 fixed point sampling stations in England and Scotland and continuous plankton recorder surveys which take place across the Northern and Celtic Seas and other parts of the world (Marine Biological Association 2023). Plankton biomass estimates are based upon the biomass of copepod species for zooplankton and chlorophyll concentrations or colour index for phytoplankton. The plankton species composition indicator, meanwhile, is based upon multiple region- and species-specific state-based models of two ecologically relevant lifeforms that share similar functional traits, allowing researchers the ability to track changes in species composition over time. In both cases no specific assessment thresholds have been defined owing to difficulties in strictly defining GES for these indicators. Nonetheless, some of the constituent values, such as shifts in the dominance of dinoflagellates relative to diatoms, may provide some indication of the presence of region-specific problems like eutrophication.

Table 14: Pelagic habitats indicators, targets and monitoring programs

Indicator	Targets	Monitoring Programs and Methods
Plankton biomass	Changes in plankton biomass and abundance ● There is no fixed assessment threshold ● Changes are classified as small (between the 25^{th} and 75^{th} percentiles), important (between the 5^{th} and 25^{th} or 75^{th} and 95^{th} percentiles) or extreme (below the 5^{th} or above the 95^{th} percentiles)	Fixed point sampling; Continuous Plankton Recorder; Other plankton monitoring programs ● Zooplankton biomass is based on copepod species abundance ● Phytoplankton is based on chlorophyll a or the phytoplankton colour index ● Fixed point and continuous plankton recorder data are not integrated for the assessment

	• Separate analyses for zooplankton and phytoplankton	
Plankton communities	Changes in the species composition of plankton communities • Changes in plankton index from baseline • Baseline defined as period between 2004-2008 • Plankton index is calculated for different combinations of lifeforms, habitat types and regions	Fixed point sampling; Continuous Plankton Recorder; Other plankton monitoring programs • State-space models of two lifeforms with similar functional traits are used to calculate individual plankton indexes • Fixed point and continuous plankton recorder data are not integrated for the assessment

Benthic Habitats

Monitoring and evaluation of benthic habitats under the UK marine strategy take place under a number of monitoring programs, covering a wide range of different indicators concerning the ecological quality of intertidal seagrass, saltmarsh and rocky shore communities, subtidal habitats and infaunal communities, the status of physical damage to the seafloor and biogenic habitats, and an intertidal community index of rocky shore communities that can generate insights about the impacts of climate change. Intertidal community monitoring, apart from the community temperature index, takes place under requirements and methods established by the Water Framework Directive, which has developed habitat specific indices and targets based upon a range of parameters, including their extent and rate of change, species diversity and value relative to historical baselines. For example, the target for intertidal seagrass is that 95% of surface areas have an ecological quality ratio greater than 0.60, which is in turn based upon changes in the extent of seagrass beds, shoot density, and species diversity. In contrast, subtidal habitat monitoring is generally less well developed and focuses more on monitoring of pressures in relation to physical damage of the seafloor, and overlap between human activities and biogenic habitats (i.e., horse mussel reefs and seagrass). For example, the UK marine strategy has established a target that less than 15% of the seafloor is exposed to high levels of anthropogenic disturbances, and examines these

Table 15: Benthic indicators, targets and monitoring programs

Indicator	Targets	Monitoring Programs and Methods
Intertidal community index	Community Temperature Index of intertidal rocky shore communities meet or exceed predictions based on 1.5° C	Marine biodiversity and Climate change (MarClim) Monitoring Programme ● The Community Temperature Index is a measure of the status of a community regarding its species composition of cold- and warm-water species
Intertidal seagrass	Greater than 95% of surface areas assessed meet ecological quality ratio >0.60 based on the average of three criteria: extent of seagrass bed loss, annual/five-yearly average shoot density loss, and species loss as a proportion of a historical reference.	Monitoring program follows protocols developed by the Water Framework Directive ● Intertidal seagrass tool
Intertidal saltmarsh	Greater than 95% of surface areas assessed meet ecological quality ratio >0.60 based on the average of saltmarsh extent (current proportion of historical extent and extent change), proportions of zones present, dominant zone extent as a proportion of the total extent and taxa number as a proportion of a historical reference	Monitoring program follows protocols developed by the Water Framework Directive ● Intertidal saltmarsh tool
Intertidal rocky shore	85% of surveys achieve Ecological Quality Ratio ≥0.60 or Good Ecological Potential (for Heavily Modified Water Bodies) based on macroalgae communities	Monitoring program follows protocols developed by the Water Framework Directive ● Intertidal rocky shore macroalgal index
Subtidal habitats	No assessment thresholds have been determined	Infaunal data collected using grab and box core sampling ● Diversity index is calculated based on species richness and abundance
Physical damage	Less than 15% of seafloor exposed to high levels of anthropogenic disturbances	Monitoring program leverages observed and modelled data and requires information on: ● Habitat types and their distribution ● Sensitivity of different habitats to disturbances ● Distribution and intensity of pressures
Infaunal quality index	85% of assessed survey areas have Ecological Quality Ratio ≥	Monitoring program combines data collected for the Water Framework Directive, Clean Seas

Indicator	Targets	Monitoring Programs and Methods
	0.64 or Good Ecological Potential (for Heavily Modified Water Bodies)	Environmental Monitoring Programme and other data sources ● Infaunal quality index classification scheme
Physical loss	Biogenic seafloor habitats are stable or increasing and not smaller than the baseline value Biogenic habitats covered ● Seagrass beds ● Horse mussel reefs	Data on horse mussel reefs and seagrass distributions are used to model potential habitats across UK waters, and combined with data on human activities that could potentially cause loss of habitat. ● Overlap in potential habitat and human activities

Non-native Species

The UK marine strategy reports on the number of newly recorded non-native species by compiling data from secondary sources, including scientific studies and citizen science or other types of reports. This information is used to generate estimates of the number of new non-native species found in Celtic Seas and Greater North Sea region each year and cumulatively over a reporting period. To date, no specific assessment thresholds have been defined.

Table 16: Non-native species indicators, targets and monitoring programs

Indicator	Targets	Monitoring Programs and Methods
Newly recorded non-native species	Reduction in the risk of introduction and spread of non-native species ● No specific assessment threshold has been defined	Compilation of data from secondary sources, including scientific studies, citizen science or other reports

Populations of Commercial fish and Shellfish

The UK marine strategy monitors the status and trends of commercial fish species by tracking levels of fishing and spawning stock biomass across 57 marine fish and 59 shellfish fish stocks. In general, the targets aim to increase the number of stocks that are fished at sustainable levels (i.e., maximum sustainable yield), increase the number of stocks with spawning stock biomass that are at or above their respective maximum sustainable yields, and reduce the number of stocks for which these values are unknown or uncertain. Data to support this analysis are provided by ICES stock estimates for internationally straddling fish stocks and national assessments of shellfish stocks.

Table 17: Commercial fish indicators, targets and monitoring programs

Indicator	Targets	Monitoring Programs and Methods

Fishing pressure	Increase the proportion of stocks fished at or below FMSY and zero stocks of unknown status relative to FMSY • Covers 57 marine fish stocks and 59 shellfish stocks	ICES and national stock assessments • Aggregation of fish stock assessments
Reproductive capacity	Increase proportion of stocks with spawning stock biomass at or above MSY and zero stocks with unknown status • Covers 57 marine fish stocks and 59 shellfish stocks	ICES and national stock assessments • Aggregation of fish stock assessments

Elements of Marine Food Webs

The UK marine strategy monitors the status and trends of marine food webs by tracking trends in the abundance and characteristics of different species, including birds, fish, cetacean, seals and plankton which are outlined in Table 18. These indicators are identical to other indicators that are used to assess biological diversity and pelagic habitats, although it is worth noting that species composition in fish communities and changes in plankton communities were explicitly developed as an indicator of food webs and “borrowed” by the other descriptor.

Table 18: Food web indicators, targets and monitoring programs

Indicator	Targets	Monitoring Programs and Methods
Marine bird abundance	Changes in abundance of marine birds should be within individual target levels in 75% of species monitored. Species-specific thresholds are used • 0.8 of baseline (1992) for species that lay one egg • 0.7 of baseline (1992) for species that lay more than 1 egg • Includes 127 indicators that distinguishes between species, location and breeding/non-breeding abundance	Seabird Monitoring Programme (SMP); Wetland Bird Survey (WeBS); Periodic bird surveys; Breeding Atlas; Non-Estuarine Waterbird Survey; Data from OSPAR contracting parties • Missing data was estimated using statistical models • Count of breeding pairs or adults per species per colony per year for breeding bird species Numbers of birds, per species, per site, and per year that are counted from the land or the air for non-breeding bird species
Seal abundance and distribution	Seal abundance decline of less than 1% per year over a six-year period	Seal Population Monitoring Program

Indicator	Targets	Monitoring Programs and Methods
	Seal abundance decline of less than 25% from baseline year. Presence at haul-out and breeding sites (no specific target) ● Species covered include grey seal and harbour seal	● Land based counts during moulting (harbour seal) or breeding (grey seal) Total abundance of grey seals is modelled using summer counts of grey seals and counts of pups in autumn and winter
Cetacean abundance and distribution	No decrease of greater than 5% over a ten-year period Species covered include harbour porpoise, offshore bottlenose dolphin, short-beaked common dolphin, striped dolphin, white-beaked dolphin, minke whale. fin whale, long-finned pilot whale. beaked whale and sperm whale	Small Cetaceans in European Atlantic waters and the North Sea (SCANS) surveys; CODA (Cetacean Offshore Distribution and Abundance in the European Atlantic; North Atlantic Sightings Surveys (NASS); Norwegian Independent Line Transect Surveys (NILS) for minke whales. ● Aerial or shipboard surveys ● Abundance estimates generated using the point (or track line) independence model At least 3 abundance estimates across different years in a 10 year period are required
Inshore bottlenose dolphin abundance	No decrease of greater than 5% over a ten-year period	Bottlenose dolphin inshore population monitoring ● Photo identification ● Line transects ● Capture-recapture At least 4 abundance estimates across different years in a 10 year period are required
Changes in plankton communities	Changes in the species composition of plankton communities ● Changes in plankton index from baseline ● Baseline defined as period between 2004-2008 Plankton index is calculated for different combinations of lifeforms, habitat types and regions	Fixed point sampling; Continuous Plankton Recorder; Other plankton monitoring programs ● State-space models of two lifeforms with similar functional traits are used to calculate individual plankton indexes Fixed point and continuous plankton recorder data are not integrated for the assessment
Size composition in fish communities	No change in the size composition of fish communities based on trends with respect to typical length. ● Indicator has 4 values (long term decrease to a minimum state, long term	Scientific fisheries surveys using otter trawl and beam trawl, including the International Bottom Trawl Survey programme ● Indicator is aggregated at the survey level. ● Trends are modelled using locally weighted scatterplot and breakpoint analyses were used to identify changes.

Indicator	Targets	Monitoring Programs and Methods
	decrease, long-term increase or no change) • Distinguishes between pelagic and demersal communities and region	
Species composition in fish communities	No change in the size composition of fish communities based on trends in mean maximum length • Indicator has 4 values (long term decrease to a minimum state, long term decrease, long-term increase or no change) • Distinguishes between pelagic and demersal communities and between the Greater North and Celtic Seas	Scientific fisheries surveys using otter trawl and beam trawl, including the International Bottom Trawl Survey programme • Indicator is aggregated at the survey level. • Trends are modelled using locally weighted scatterplot and breakpoint analyses were used to identify changes.
Large fish index	Size-composition of fish communities should reflect a healthy status and no change in the size composition of fish communities based on large fish index (LFI) LFI measures proportion of large fish in a survey, where large fish are defined for each survey and exclude certain species or types thereof	Scientific fisheries surveys using otter trawl and beam trawl, including the International Bottom Trawl Survey programme • Indicator is aggregated at the survey level. Assessment thresholds were set using a variety of methods, including 3 X lowest five year moving average, reference values, long-term correlations or trend-based analysis
Kittiwake breeding success	Number of chicks fledged per pair is not significantly different, statistically, from levels expected under prevailing climatic conditions such as sea surface temperature.	Seabird Monitoring Programme of the UK and Ireland; Sea Surface Temperature datasets • Count of fledged chicks per colony • Missing years are estimated by statistical models • Baseline is estimated using a statistical model sea surface temperature
Marine bird breeding success	Less than 5% (or 15 year mean for terns) of colonies experiencing breeding failure • Breeding failure is defined as annual mean breeding	Seabird Monitoring Programme of the UK, Ireland and European partners • Count of fledged chicks per colony • Missing years are estimated by statistical models

Indicator	Targets	Monitoring Programs and Methods
	success of less than 0.1 chicks per pair ● Covers over 20 species	
Grey seal pup production	Grey seal pup production decline of less than 1% per year over a six-year period Grey seal pup production decline of less than 25% from baseline year.	Seal Population Monitoring Program ● Aerial surveys ● Ground or boat-based counts ● Estimates of total pup production are modelled for each colony

Eutrophication

Monitoring of eutrophication under the UK marine strategy takes place under the guidance of the Clean Seas Environment Monitoring programme, following guidelines established by OSPAR. Physical samples are collected using research vessels and at research stations. However, eutrophication monitoring as part of the UK marine strategy is increasingly deploying remote technologies and tools, including SmartBuoys, and benthic landers in key locations to track real-time concentrations of nutrients and chlorophyll, contributing to monitoring efficiencies and better understanding of nutrient and chlorophyll dynamics in the growing season.

Table 19: Eutrophication indicators, targets and monitoring programs

Indicator	Targets	Monitoring Programs and Methods
Chlorophyll	No increase in the chlorophyll 90th percentile in the growing season	Risk based monitoring by the Clean Seas Environment Monitoring Programme ● Samples collected using ships, submersible sensors and continuous data from SmartBuoys ● Satellite-based remote sensing ● Samples analyzed with fluorometry, spectrophotometry and pigment analysis
Dissolved oxygen	Oxygen concentrations in bottom waters are above area-specific oxygen assessment levels (4 to 6 mg/l) No benthic species mortality events resulting from oxygen deficiency directly related to anthropogenic	Risk based monitoring by the Clean Seas Environment Monitoring Programme ● Samples collected from ships, stations and continuous data from benthic landers
Nutrient concentrations	No increase in dissolved inorganic nitrogen and phosphorus concentrations	Risk based monitoring by the Clean Seas Environment Monitoring Programme

		• Samples collected at cruise stations and continuous data from SmartBuoys • Mann-Kendall tests are used to analyze trends
Nutrient inputs	No formal target for nutrient inputs • General expectation that nutrient inputs will not increase or contribute to enrichment, and downward trend in problem areas	Monitoring of riverine inputs and direct discharges from point sources (i.e., industry, sewage) • Samples collected for each river and aggregated at different scales • Mann-Kendall tests are used to analyze trends

Alteration of Hydrographical Conditions

Monitoring programs for hydrographical conditions have not been developed to date.

Concentrations of Contaminants

Monitoring of contaminants as part of the UK Marine Strategy is led to a great extent by the UK Clean Seas Environmental Monitoring Programme which monitors the quality of the UK's coastal and offshore waters, including the levels of pollutants, nutrients, and other contaminants present in the water, sediments, and biota. The Programme has been in operation since 1988 and collects data from a network of monitoring sites around the UK coast, including estuaries, harbours, and open waters. The Programme monitors a range of parameters, including physical and chemical characteristics of the water, the concentration of pollutants and other contaminants, and the abundance and diversity of marine organisms. Pollutants covered by the marine strategy include polychlorinated biphenyls (PCBs), in polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenyl ethers (PBDEs), and radionuclides. In general targets aim to ensure that concentrations of contaminants are below concentrations at which adverse effects are likely to occur, which are defined by different sources including OSPAR and the US EPA. Contaminant concentrations in biota are also examined and a range of bioindicators and methods have been developed to track specific or general levels of contaminants, including bile metabolites EROD enzyme activity, external fish disease, liver neoplasms and micronucleus in a selection of groundfish species and imposex in dog whelk.

Table 20: Contaminants indicators, targets and monitoring programs

Indicator	Targets	Monitoring Programs and Methods
PAHs in biota	Concentrations are below the concentrations at which adverse effects are likely to occur	UK Clean Seas Environment Monitoring Programme • Site data are combined to generate a mean estimate for each biogeographic region using a linear mixed model

Indicator	Targets	Monitoring Programs and Methods
	• OSPAR's environmental assessment criteria were used	
PAHs in sediment	Concentrations are below the concentrations at which adverse effects are likely to occur • US EPA Effects-Range-Low values were used	UK Clean Seas Environment Monitoring Programme • Site data are combined to generate a mean estimate for each biogeographic region using a linear mixed model
PBDEs in biota	There are no current targets	UK Clean Seas Environment Monitoring Programme
PBDEs in sediment	There are no current targets	UK Clean Seas Environment Monitoring Programme
PCBs in biota	Concentrations are below the concentrations at which adverse effects are likely to occur • OSPAR's environmental assessment criteria were used	UK Clean Seas Environment Monitoring Programme • PCBs are monitored in mussels and fish • Site data are combined to generate a mean estimate for each biogeographic region using a linear mixed model
PCBs in sediment	Concentrations are below the concentrations at which adverse effects are likely to occur • OSPAR's environmental assessment criteria were used	UK Clean Seas Environment Monitoring Programme • Site data are combined to generate a mean estimate for each biogeographic region using a linear mixed model
Radionuclides	Concentrations are below the concentrations at which adverse effects are likely to occur • Radiological doses received by people and wildlife are below UK	Methods described in the Radioactivity in Food and the Environment report series reports.
Coastal waters	Concentrations are below the concentrations at which adverse effects are likely to occur • Contaminants include PAHs, lindane, tributyltin, mercury and cypermethrin • Based on environmental quality standards described in EU Priority Substances Directive	Surface water monitoring carried out following Guidance on Surface Water Monitoring under the Water Framework Directive"

Indicator	Targets	Monitoring Programs and Methods
Bile metabolites	The intensity of biological or ecological effects are below the toxicologically-based standards ● OSPAR's environmental assessment criteria were used	UK Clean Seas Environment Monitoring Programme ● Polycyclic aromatic hydrocarbon metabolites in bile of common dab and flounder are assessed ● Site data are combined to generate a mean estimate for each biogeographic region
Biological effects (EROD enzyme activity) in fish	The intensity of biological or ecological effects are below the toxicologically-based standards ● OSPAR's environmental assessment criteria were used	UK Clean Seas Environment Monitoring Programme ● Sampling of dab, flounder and plaice is undertaken at coastal and offshore monitoring stations ● EROD concentrations in liver are assessed following ICES techniques
External fish disease	The intensity of biological or ecological effects are below the toxicologically based standards ● Covers dab, flounder and cod ● OSPAR's and ICES environmental assessment criteria were used	UK Clean Seas Environment Monitoring Programme ● Research cruises collect and visually analyze fish for evidence of diseases, ● Only dab has been used in analyses due to the lack of assessment criteria for flounder, and small number of cod
Imposex	The intensity of biological or ecological effects are below the toxicologically based standards ● Imposex in dogwhelks are close to background levels ● OSPAR's environmental assessment criteria were used	Risk-based monitoring at intertidal monitoring stations ● Samples are analyzed to determine the number and percentage of sterile females
Liver neoplasms	The intensity of biological or ecological effects are below the toxicologically based standards ● Prevalence of liver neoplasms in dab and their trends ● Prevalance is categorized into three groups, background, elevated and significant	UK Clean Seas Environment Monitoring Programme ● Samples collected from 43 fishing stations in coastal and offshore waters ● Analysis of fish livers to determine the number and percentage of fish with liver neoplasms, controlling for age and sex
Metal inputs	There are no current targets	Risk-based monitoring of inputs from rivers and direct discharges and estimates of atmospheric loading ● Estimates were not updated in the most recent assessments due to insufficient data

Indicator	Targets	Monitoring Programs and Methods
	• General objective to reduce pollution from cadmium, mercury and leading	
Metals in biota	Concentrations of contaminants are below levels at which adverse effects are likely to occur to sea life • Covers cadmium, mercury and lead concentrations in mussels and fish • European commission food standards were used as thresholds • Status and trends are assessed	Risk-based monitoring by UK Clean Seas Environmental Monitoring Program • Samples of blue mussels, dab, plaice and flounder are collected and analyzed using OSPAR guidance • Time series are assessed by fitting a parametric model
Metals in sediment	Concentrations of contaminants are below levels at which adverse effects are likely to occur to sea life • Covers cadmium, mercury and lead concentrations in sediments • OSPAR environmental assessment criteria are used • Includes status and trends	Risk-based monitoring by UK Clean Seas Environmental Monitoring Program • Muddy sediments are collected from monitoring station and analyzed following OSPAR guidance • Most stations are monitored annually
Micronucleus	Concentrations of contaminants are below levels at which adverse effects are likely to occur to sea life • Covers micronucleus in flounder and dab against background assessment criteria • Exposure levels are based on the percentage of fish exceeding background assessment criteria	Risk-based monitoring by UK Clean Seas Environmental Monitoring Program • Fish are sampled at fixed sampling stations Micronucleues assay are used and compared to a background threshold • Data is aggregated for 8 regions
Oil spills	The occurrence and extent of significant acute and their impact on biota should be minimised • There are no specific assessment thresholds • Monitors quantity and trends	Oil spill data from shipping, ports and offshore oil and gas are reported to the UK Maritime and Coast Guard Agency • Reports sector-specific spill amounts and their distribution across different sizes of spills

Contaminants in Seafood

Contaminants in seafood are assessed through samples collected from commercial fishing grounds in the Celtic Sea and Greater North Sea and the Billingsgate fish market in London where the locations of the catch were known. Seafood known to be at greatest risk of accumulating contaminants were targeted for sampling and analysis, including sardines, sea bass, dogfish, mackerel, herring, sprats, halibut, turbot, and grey mullet. Contaminant concentrations, including cadmium, mercury, lead, trace metals, and dioxins are assessed in relation to regulatory levels established through legislation.

Table 21: Contaminants in seafood indicators, targets and monitoring programs

Indicator	Targets	Monitoring Programs and Methods
Contaminants in seafood	High rates of compliance with relevant seafood contaminant concentration regulations ● Target species include sardines, sea bass, dogfish, mackerel, herring, sprats, halibut, turbot, and grey mullet ● Contaminants include cadmium, mercury, lead, trace metals, and dioxins ● Regulatory levels established by legislation	Samples collected from commercial fishing grounds and a fish market in London

Marine Litter

Three core indicators are used by the UK marine strategy to monitor the status and trends of litter in the marine environment. These indicators distinguish between beach litter, floating litter and seafloor litter, and each adopts a unique approach to monitoring. First floating litter is assessed on the basis of the quantity of plastics found within the stomachs of beached fulmars found along the shore by volunteer networks. Fulmars forage exclusively at sea and generally at the surface of the water, providing an ideal opportunity to track trends in floating plastic litter. Seafloor litter, meanwhile, is assessed on the basis of manual assessments of litter contained within otter trawl survey hauls and are used to inform the development of model estimates. Finally, beach litter is assessed using citizen science programs (Beachwatch in Britain and Keep Northern Ireland Beautiful in Northern Ireland) in which 100 meter sections of beach, excluding major tourist beaches, are cleaned and data on beach litter are collected (Marine Conservation Society 2023).

Table 22: Litter indicators, targets and monitoring programs

Indicator	Targets	Monitoring Programs and Methods

Beach litter	The amount of litter is reducing over time and levels do not pose a significant risk to the coastal and marine environment ● Reports litter amount, type and trends	Citizen science program Beachwatch and Keep Northern Ireland Beautiful collects details on the type and source of litter on UK beaches ● Litter is sampled across 100 meter section of beach, excluding major tourist beaches
Floating litter	The amount of litter is reducing over time and levels do not pose a significant risk to the coastal and marine environment ● Long-term goal that less than 10% of fulmars have less than 0.1g of plastics in their stomachs	OSPAR Coordinated Environmental Monitoring Programme Guidelines ● Dead beached birds are collected by volunteer networks ● Stomach contents are analyzed in the lab following OSPAR methods
Seafloor litter	The amount of litter is reducing over time and levels do not pose a significant risk to the coastal and marine environment ● Indicator assesses the amount and occurrence of litter	Otter trawl surveys with manual collection of litter items ● Probability haul contains plastic and median total litter per haul is estimated and smoothed using a generalized linear model.

Input of Anthropogenic Sound

The final descriptor for the UK Marine Strategy relates to anthropogenic sound in the marine environment, including impulsive and ambient noise. Impulsive noise resulting from seismic surveys, sub-bottom profiling, impact pile driving, unclassified defence activities, explosives, acoustic deterrence, and some echosounders are now required to report noise events to the Marine Noise Registry, which enables estimates of the distribution and concentration of impulsive noise events in the marine environment (JNCC 2023). Ambient noise, meanwhile, is assessed on the basis of data collected from 11 temporary ambient noise monitoring stations that were mostly concentrated in the Northern North Sea surrounding Scotland.

Table 23: Anthropogenic sound indicators, targets and monitoring programs

Indicator	Targets	Monitoring Programs and Methods
Impulsive noise	Establishment of Marine Noise Registry ● No specific targets have been defined ● Covers 7 sources including seismic surveys, sub-bottom profiling, impact pile driving, unclassified defence	Marine Noise Registry ● Collects details on impulsive noise events ● Enables reporting of noise events per block day

	activities, explosives, acoustic deterrence, some echosounders	
Ambient noise	No targets have been defined	11 Ambient Noise Monitoring Stations ● Underwater acoustic recorders are used to collect ambient noise data

Case Study 4:

Victoria, Australia MPAN Monitoring

Ecklonia Reef Life Survey, Cape Howe, Australia, Credit: Parks Victoria

Key Lessons from this Case Study

A rigorous adaptive management approach can be applied to MPA management as well as its monitoring programs. Monitoring programs were subject to periodic review and reassessment to ensure management relevance, technical rigor, and cost-efficiency, and adoption of emerging global best practices.

Monitoring program review is a multitiered process that can be applied 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.

Monitoring program review should consider emerging tools and technologies and how they may best complement or replace historical methods. This process can be facilitated by early and ongoing pilot testing of emerging methods.

Monitoring review should include a standardized monitoring prioritization protocol to help align monitoring activities with the highest management priorities and scale monitoring effort to available resources.

Insights from monitoring review highlight the importance of gaining efficiencies to more directly support action. This includes refining indicators to reduce redundancy, streamlining sampling designs using tiered methods and sentinel sites, and linking indicators to management objectives, thresholds, and triggers to more explicitly link management objectives to actions.

Background

Australia has long been at the forefront of the science and management of marine protected areas, particularly following the establishment of the Great Barrier Reef Marine Park in 1975. Accelerating interest in marine protection has resulted in the addition of many more marine protected areas in Australian waters since, culminating in the declaration of a National Representative System of Marine Protected Areas in 2013 which came under full protection in 2018 (Albrecht et al. 2021). Today, Australia has a comprehensive network of marine protected areas encompassing national, state, and territorial marine parks across tropical and temperate waters. Its 58 national Australian Marine Parks (AMPs) are grouped into five regional networks and the Great Barrier Reef Marine Park located in Commonwealth waters (3 nautical miles from shore to the edge of its exclusive economic zone (EEZ), **Figure 9**), which are managed by Parks Australia. Its state marine protected areas are designated using different names and management systems by jurisdiction (e.g., Marine National Parks and Marine Sanctuaries in Victoria; Marine Parks, Aquatic Reserves, and National Parks and Nature Reserves in New South Wales) and located in nearshore state waters (shoreline to three nautical miles from shore). Both national and state marine protected areas include a mix of no-take and multiple use areas. (Hayes et al. 2021, Howe et al. 2023). This case study will focus on the system of marine protected areas within the state waters of **Victoria**, which was the first to declare such a large system of marine protected areas within one jurisdiction in 2002 and which has recently completed a **20-year review and prioritization of its MPA system's Monitoring, Evaluation, and Reporting (MER) program** that offers insights for monitoring design in new MPAN contexts (Wescott 2006, Howe et al. 2023).

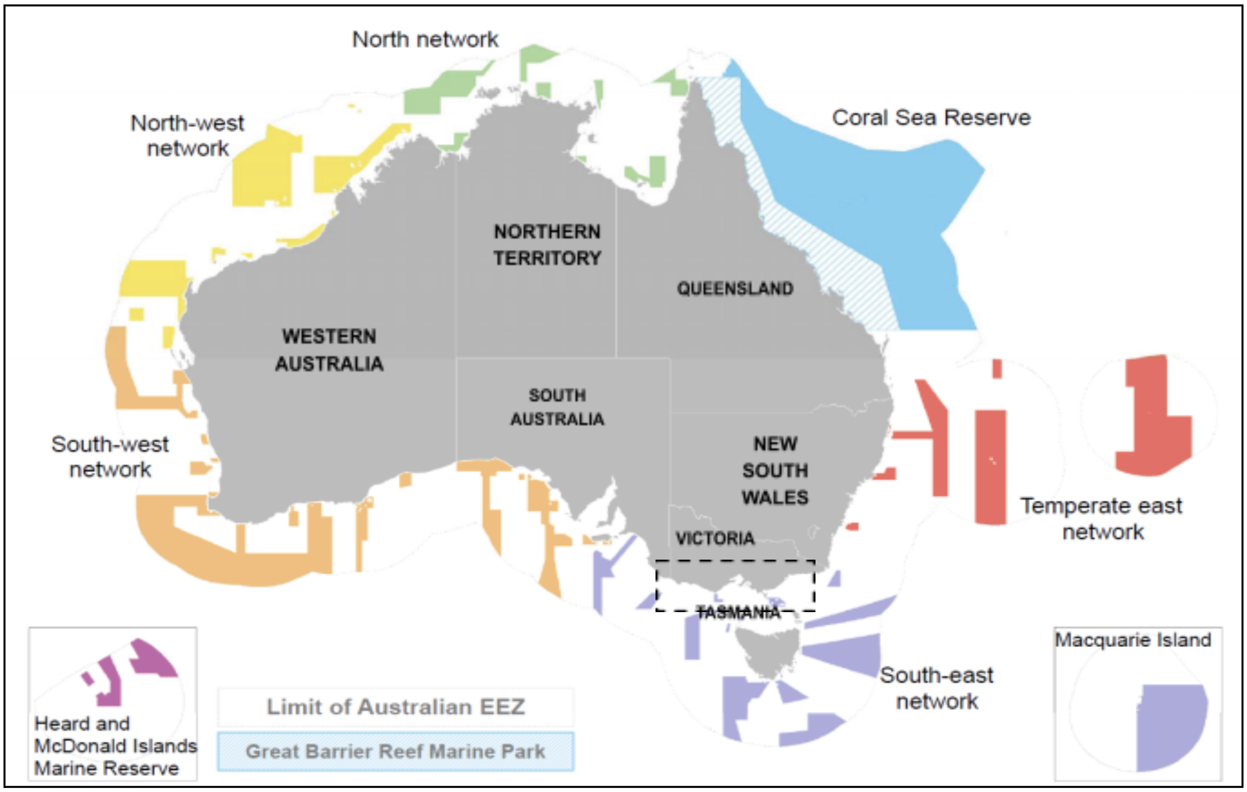


Figure 9: Australia's national network of Australian Marine Parks (AMPs) located in Commonwealth waters. The area in the dashed box is enlarged in the following figure. (Credit: Parliament of Australia).

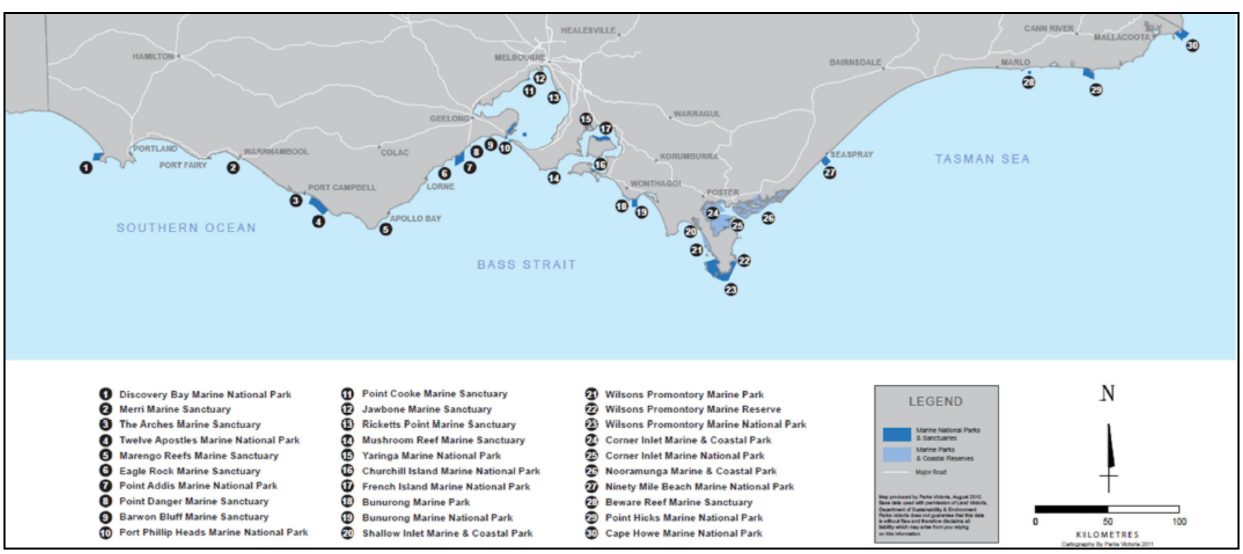


Figure 10: The state of Victoria's network of marine protected areas, comprising 24 Marine National Parks and Sanctuaries, 6 other MPAs comprising 3 Marine and Coastal Parks, 2 Marine Parks and 1 Marine Reserve (Credit: Howe et al. 2023).

NOTE TO READERS: Much of the information summarized below is drawn from a draft report kindly shared by Parks Victoria (Howe et al. 2023), and the final contents of said report planned to be published as part of the Parks Victoria Technical Series may differ slightly from the contents of this case study.

Parks Victoria's MPA Monitoring, Evaluation and Reporting Program

The Evolution of Victoria's MER Program

Monitoring, evaluation, and reporting plays a vital role in evaluating management effectiveness and informing evidence-based management. The core components of Victoria's original MER program were initiated as far back as 1998, prior to designation of the network in 2002. In these early years, monitoring focused mainly on subtidal and intertidal reefs across many MPAs, but focused on a small though ecologically and socially important proportion of each park's area (Howe et al. 2023). The original monitoring program has evolved over time as management strategies matured, new information emerged, and ongoing review provided insights to guide refinements to current practice as part of good adaptive management (Howe et al. 2023).

A review of management priorities led to a shift towards action-oriented planning using the Nature Conservancy's **Conservation Action Planning (CAP)** framework which draws a clearer line of sight from plans to actions 'on the ground'.. Adoption of this framework led to the development of interim Conservation Action Plans (CAPs) for each park in 2013, which in turn prompted a more comprehensive review and update of the MER program between 2015 and the present to better align monitoring priorities with this new asset-led approach to conservation outcomes. This process assessed the value of information delivered through current practice, considered the integration of new technologies, monitoring designs, and delivery models, and undertook a monitoring prioritization process to focus on gathering information relevant for the highest management priorities and ensure the best use of limited resources (Howe et al. 2023).

Monitoring Framework and Principles

Parks Victoria's MER program is driven by its Conservation Action Plans and is operationalized through two nested levels of monitoring, evaluation, and reporting that encompass both terrestrial and marine parks.

The **Signs of a Healthy Parks Program** was developed to ensure 'systematic, robust, and integrated ecological monitoring' to monitor the health of individual parks using a range of park-specific indicators. Monitoring through this program adheres to a broader monitoring framework and tiered monitoring hierarchy. The **monitoring framework** describes the relationships between three different types of monitoring carried out in each park, including activity monitoring to assess management efficiency, threat monitoring to assess management effectiveness monitoring, and natural values monitoring to assess management outcomes (**Figure 11**). This framework is paired with a tiered **monitoring hierarchy** that includes three different levels of monitoring: qualitative (e.g., observations and photo points to assess broad changes over time), semi-quantitative (e.g., approximate measures of the status and extent of threats using simple but consistent and repeatable rapid assessments), and quantitative (e.g., scientifically robust monitoring protocols to directly measure change). This hierarchy acknowledges that the intensive quantitative monitoring may not be required in all monitoring questions or contexts and identifies which levels of monitoring are appropriate given various trade-offs to prioritize the allocation of monitoring resources (Howe et al. 2023).

The related **State of the Parks (SoP) Program** provides a more holistic evaluation of Victoria's overall parks network and its effectiveness in meeting park management goals across four broad socio-ecological dimensions: Natural Values; Traditional Owner (Indigenous) Cultural Values; Historic Heritage; and Visitor Experience. This SoP approach is based on the internationally recognised Management Effectiveness Framework from the IUCN World Commission on Protected Areas (Hockings et al. 2006). An SoP assessment is completed every three years drawing on a broad range of information sources, including monitoring outcomes from the Signs of a Healthy Parks Program and other monitoring programs, park manager experiences and observations, the knowledge of specialists and experts, and the local, Indigenous and cultural knowledge of Traditional Owners and communities (Howe et al. 2023).

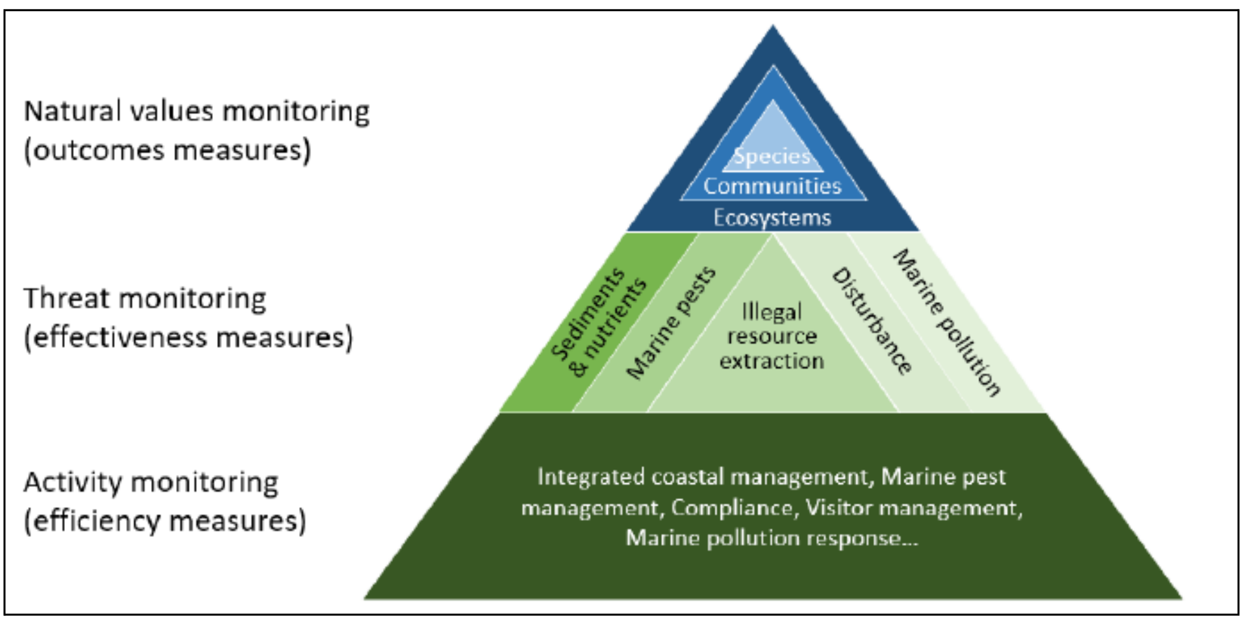


Figure 11: A framework illustrating the relationship between the three types of monitoring underpinning monitoring programs across all Parks Victoria's terrestrial and marine park monitoring programs, including its MPAs. Reproduced from Howe et al. 2023.

Monitoring Indicator Selection

The development of Conservation Action Plans (CAPs) for MPAs enabled the development of specific, park-level monitoring priorities and indicators for key ecological attributes and threats for each park. Candidate indicators were compiled from relevant literature and expert consultation and screened using a set of nine **indicator selection criteria** as a guiding framework. These included four essential Tier 1 criteria, where indicators meeting these criteria were then assessed using a further five Tier 2 criteria (Table 24).

Table 24: Parks Victoria MPA Monitoring Indicator Selection Criteria (details of rating scales available in appendices to Howe et al. 2023)

Parks Victoria MPA Monitoring Indicator Selection Criteria	
Tier 1	**Tier 2**
● Cost ● Low variability ● Link to natural value ● Low impact	● Sensitivity and responsive to threats ● State of methodology ● Used by partners ● Simplicity of methods ● Early warning (anticipatory)

Monitoring Tools and Methods

Key monitoring programs in Victoria's MPAN have relied on a wide range of methods and technologies implemented in partnership with park staff, industry contractors, academic partners, and citizen scientists. These include a combination of historical methods such as intertidal and underwater visual census and soft sediment sampling and the more recent adoption of emerging methods such as fisheries-independent trapping surveys, diver-operated video surveys, baited remote underwater video (BRUV) stations, remotely operated underwater vehicles (ROVs), and towed video (Howe et al. 2023).

Many of historical monitoring programs using these methods have undergone their own periodic review to improve their statistical rigor through the adoption of more statistically rigorous sampling designs (e.g., before-after-control-impact or BACI designs) and analyses and to increase their overall relevance to management objectives (Keogh et al. 2007, Howe et al. 2023). More recently, the development of park-level monitoring priorities and potential indicators in 2013 have also helped to inform early trials of new monitoring methods and technologies (e.g., AUVs, drones, remote sensing techniques) to help inform the ongoing indicator selection process. Many of these trials occurred as part of research programs or projects with academic partners, where lessons learned from trials led to recommendations now being used to develop in-house monitoring activities through Parks Victoria (Howe et al. 2022). As many of these are resource-intensive quantitative monitoring methods that cannot necessarily be implemented in each MPA in each year, Parks Victoria is also in the process of developing and testing a semi-quantitative Rapid Health Assessment protocol that complements more quantitative monitoring and provides a tool for parks staff to conduct more regular ‘health checks’ of the MPAs they manage and improve local capacity for tracking changes in ecosystem values and treats over time (Howe et al. 2023).

Evaluation and Reporting

The outcomes of monitoring programs are meant to inform robust evaluation and reporting frameworks to support evidence-based management. The evaluation and reporting process for Parks Victoria has evolved over the years through collaboration with science partners to adopt global best practice and facilitate the integration into regional State of the Parks reporting.

Alongside the development of Conservation Action Plans, Parks Victoria commissioned a research project to develop an initial framework for detailed reports and report cards for use in MPA evaluation and reporting. These pilot report cards incorporated a combination of quantitative, semi-quantitative, and qualitative information intended to provide timely, accurate, and reliable information on the past and present status of key indicators and make recommendations for improvement. The development of these report cards also considered the the needs of different audiences, and proposed a **tiered approach to reporting** across a spectrum of data aggregation: Level 1 reporting of highly aggregated metrics for the community, policy-makers, and park service partners; Level 2 reporting of indicators, indices, and related information for park managers and the science and research community, and finally Level 3 reporting of more disaggregated processed data and statistics for the most technical science and research audience. This initiative revealed the considerable effort required for generating detailed report cards and the project, though ultimately scaled back from its original vision of delivering reports for each MPA, provided important lessons learned that were carried forward into the most recent monitoring program review to inform contemporary approaches to reporting (Howe et al. 2023).

The use of **control charts** and **indicator thresholds** is a core element of the report card project carried forward into contemporary reporting. Control charts are simple line graphs that track a given measure (e.g., scores for an indicator) over time in relation to upper and lower ‘control limits’ or that act as triggers for management action (e.g., continuing existing monitoring, initiating additional monitoring or research to identify drivers of change, a specific management action to control the change, or even no action) (Carey et al. 2015).

Control limits may include one or more precautionary ‘warning’ limits that trigger further investigation or urgent ‘action limits’ that trigger the need for immediate action, and both are often included on a control chart. The value for these limits typically depends on the type of indicator, with natural indicators typically focused on lower limits (e.g., minimum viable population size, minimum densities in historical baseline) while threat indicators are typically based on upper limits (e.g., maximum allowable concentration of contaminants for water quality indicators), although some indicators may have both (e.g., native sea urchins which play an important role in the ecosystem at low densities but can overgraze and harm ecosystems at high densities) (Carey et al. 2015, Howe et al. 2023). Further technical guidance on statistically-sound methods for **how to establish control limits** is available in the appendices to Carey et al. (2015). In addition, control charts may be developed for both individual indicators (e.g., species abundance) and aggregate or synthetic indicators (e.g., biomass of mobile fishes, water quality index). Importantly, control limits are partly evidence based but also depend on where thresholds are set, and should also be reviewed and updated as environmental conditions and the management context changes over time.

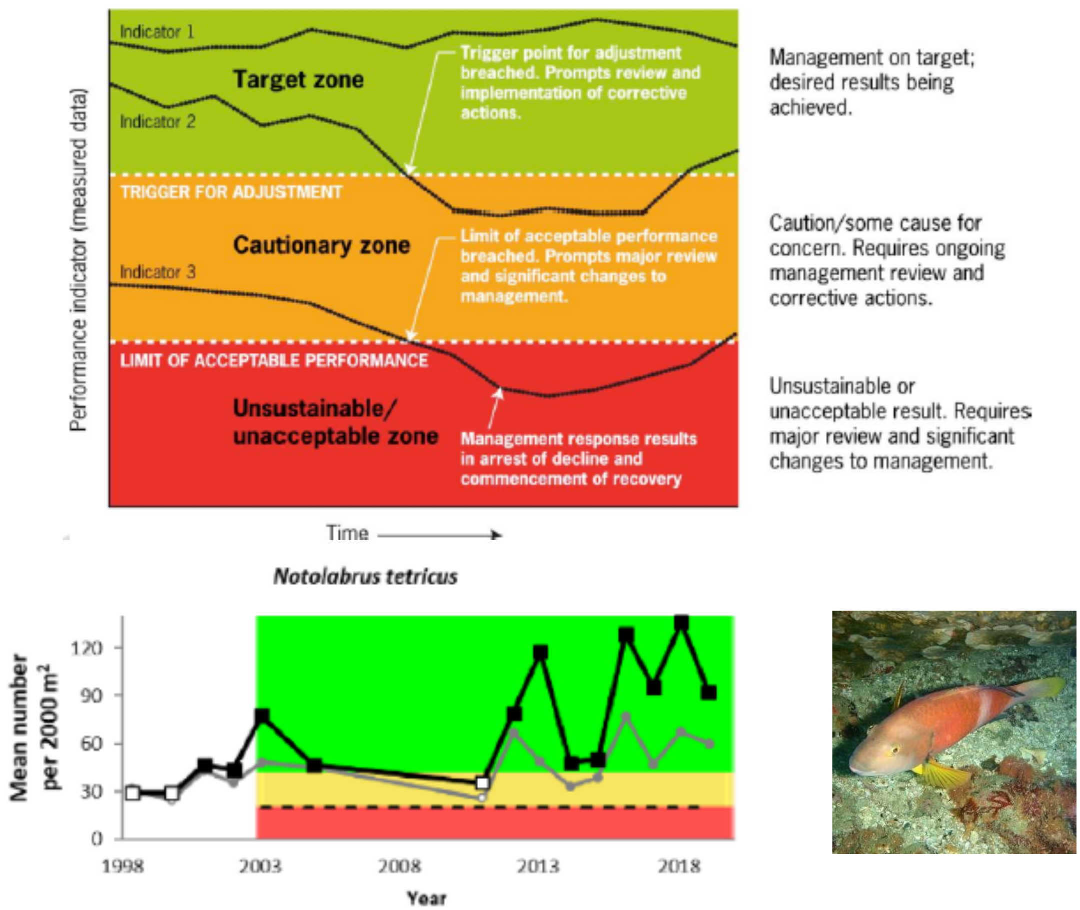


Figure 12: Traffic light style chart including thresholds or triggers for management action and an example of how it is translated into a control chart for a specific indicator, the abundance of blue-throated wrasse (*Notolabrus trtricus*) varies over time both inside (black lines) and outside (grey lines) an MPA based on diver transect data. These charts have a lower limit of acceptable change (LLAC, top of the yellow band – set as the minimum value inside the MPA from transect surveys from 1998 to 2002 prior to park establishment) and lower control limit (LCL, dashed line at top of red band) based on the variation from surveys, which indicate the level at which conditions are sufficiently poor that some management response is required. Figures reproduced from Tasmanian Parks & Wildlife Service 2013 (upper plot), Ierodiaconou et. al. 2022 (lower plot), and Wikimedia Commons (photo, used under a CC by 2.0 licence).

Control charts and limits now appear in integrated monitoring program and outcome reports for individual MPAs within Victoria's network (e.g., Young et al. 2023, Whitmarsh et al. 2023) and illustrate that it often takes 10 to 15 years or more to see a significant response for some species to protection within an MPA.

Parks Victoria publishes the results of most of its marine research and monitoring in publicly accessible Parks Victoria Technical Series reports to meet their commitment to reporting outcomes relevant to a broader audience. These technical reports are often paired with complementary communication products, including simpler research and monitoring summaries to make monitoring outcomes more accessible to a broader audience (Howe et al. 2023).

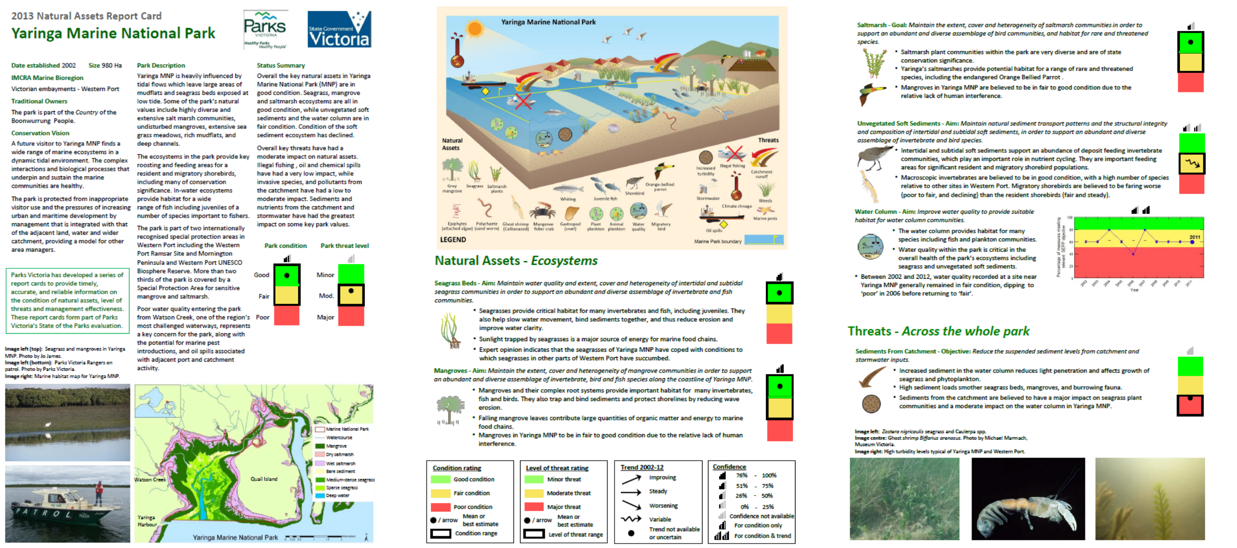


Figure 13: Sample panels from a summary report card for the Yaringa Marine National Park emerging from the report card pilot project and emphasizing visual reporting through visual conceptual models, traffic light indicator diagrams, and control charts (Reproduced from Carey et al. 2015).

Review and Redevelopment of the MER Program

The development of interim MPA Conservation Action Plans (CAPs) in 2013, the outcomes of prior reviews and audits of monitoring programs, and practical lessons learned through practical implementation of monitoring programs since their initiation prompted Parks Victoria to initiate a process in 2014 to develop a new, integrated, and streamlined state-wide monitoring program for Victoria's MPAN to better inform management (Howe et al. 2023).

Monitoring Prioritization

While CAPs identify monitoring priorities and indicators specific to each MPA, it was not practical to monitor all of these many indicators at a statewide scale. For this reason, the review and redevelopment process began with a **monitoring prioritization process** to identify the subset of those indicators representing the highest priorities for inclusion in a network-scale monitoring program. A monitoring prioritization process was developed and endorsed under the oversight of Parks Victoria's Science and Management Effectiveness Advisory Committee (SMEAC) and included three progressive stages of prioritization:

- **First Pass – Prioritizing Sites:** The first pass aimed to prioritize MPAs themselves as the basic unit of management. Based on management objectives emphasizing representation across habitats, the objective was to have at least one MPA from each marine bioregion identified as a priority or 'sentinel' MPA.

- **Second Pass – Prioritizing Values:** The second pass aimed to prioritize key ecological variables and indicators among the MPAs short-listed in the first pass.

- **Third Pass – Prioritizing Threats:** The second pass aimed to prioritize key threat variables and indicators relevant to the key ecological values short-listed in the second pass.

Prioritization was carried out using one standard set of prioritization criteria, where different subsets of criteria were applied to each step and used as a guide rather than a rigid screening tool. This prioritization process ultimately identified **five sentinel sites** to prioritize for statewide monitoring, though it was intended that other monitoring priorities for each MPA would still be addressed at a site scale through a wide range of delivery models whenever possible (Howe et al. 2023).

Table 25: Monitoring prioritization criteria used to identify a subset of monitoring priorities for a state-wide MPA monitoring program for Victoria's Marine National Parks and Sanctuaries (details of rating scales available in appendices to Howe et al. 2023).

No.	Criteria	1st Pass Priority MPAs	2nd Pass Priority Values	3rd Pass Priority Threats
1	Protection level / IUCN category of the Marine Protected Area?	✔		
2	Does the park include significant values that are at risk? / Is it a significant value?	✔	✔	
3	What is the current level of investment in management or if there is currently limited management are there feasible management options available?	✔	✔	✔
4	What is the overall level of risk to the values/ecosystems in the park to various threats?	✔		✔
5	Is the park high profile and particularly important to the community/important for social values?	✔		
6	Will monitoring programs help demonstrate the benefit of MPAs to biodiversity conservation and any secondary benefits beyond park boundaries?		✔	✔

No.	Criteria	1st Pass Priority MPAs	2nd Pass Priority Values	3rd Pass Priority Threats
7	Does the values /threat fall within a broader landscape scale monitoring program or programs being implemented by others where the data can be used by Parks Victoria?		✔	✔
8	Does Parks Victoria and its partners have the capacity to commit to a long-term monitoring program?		✔	✔
9	Are there existing valuable long term monitoring data sets for the ecosystem/park?		✔	✔
10	What are the likely costs of the delivery options for the monitoring program(s) (for values and threats)?		✔	✔
11	Are there any key emerging threats where Parks Victoria should have a monitoring program in place to allow it to assess the impact on key park values and respond in a timely manner?			✔

Revised Sampling and Evaluation Approach

Key Evaluation Questions

Once sentinel sites and key indicators were identified, it was also necessary to re-evaluate the optimal spatial and temporal sampling design to ensure statistically rigorous results and assess which monitoring methods and delivery models were most suitable. The overall goal for this process was to **maximize the statistical power to detect change** in the control charts with **high confidence** around whether indicators are within established control limits (Howe et al. 2023). To achieve this, the results of prior reviews of individual monitoring programs were carried forward to recommend sampling and analytical approaches for the state-wide program. Evaluation focused on **two key questions** and their associated statistical analysis methods, which in turn drove recommendations for field sampling design to meet the conditions of those analyses with sufficient statistical rigor (Keogh et al. 2007):

- **Is there a difference between samples taken inside / outside of an MPA for a given variable at any given time?** This comparison is evaluated using paired statistical tests

- **Is there a change over time when comparing samples taken inside the MPA relative to reference sites outside the MPA?** This trend over time was to be evaluated using (1) a Before-After-Control-Impact (BACI) design with an mBACI statistical test to determine the effects of the impact, in this case MPA establishment, and (2) a regression analysis to compare trajectories over time inside and outside MPAs. When ‘before’ data prior to MPA establishment is not available, similar analyses are possible for comparing data from time periods sooner or later after establishment (Power and Boxshall 2007).

Selection of Reference Sites

Sampling design also considered the **role of reference sites** outside of MPAs in assessing effectiveness based on the management context of each site. As part of prior assessments of Victoria's MPAN, assessors acknowledged that MPAs may play different roles based on the history of the site that influence the expected outcomes of effectiveness analyses. MPAs placed in historically degraded areas are said to play a '**remedial' role**, where the primary changes following protection are expected to accrue *inside* the MPA as the release of pressures supports recovery, whereas those placed in more pristine areas play an **'insurance' role**, where the primary changes following protection are expected to accrue *outside* the MPA as the potential rise of pressures in previously pristine but unprotected areas leads to degradation. In both cases, an "MPA effect" may be expected when enforced (or 'de-facto') management regimes differ inside versus outside the MPA (Fairweather et al. 2012a,b). In general reference sites 'outside' of MPAs are on the order of hundreds of meters away from MPA boundaries.

Parks Victoria developed the following guidelines to help determine when and how reference sites should be used for a monitoring program in relation to management actions, which were used alongside other considerations about the level of management influence over values and threats and potential trade-offs required for optimal survey design (Howe et al. 2023):

- Reference sites may be established for an evaluation purpose **where differences between MPA and reference sites are expected** based on different management regimes inside and outside MPAs, where little or no difference where one is expected should trigger a management response. This is more typical of a 'remedial' MPA, but may also occur in an 'insurance' MPA under specific circumstances, for example, if changes in coastal development create a sudden increase in a human activity in the region that is a known threat to marine environments but is excluded from the MPA.
- Data from reference sites may help to **determine control limits** for monitoring inside MPAs based on observations of undesirable outcomes at the reference sites (e.g., observed levels of population decline that lead to broader population persistence or ecosystem effects at higher fishing pressures at reference sites).
- Data from reference sites may be used to understand broader trends and processes in threats and drivers that may be affecting values of interest both inside and outside of MPAs.

It is also important to try and place reference sites within similar habitat types as sites to be monitored within MPAs to improve the relevance of inside-outside comparisons. This can be challenging, depending on the type of habitat and MPA size, particularly for patchy habitats that are completely contained within MPA boundaries by design.

Revised Sampling Design and Data Management Approach

To meet the needs of these evaluation questions and analyses, and to reduce the influence of variation over short timescales, the recommended field sampling design involved a repeating pattern of **alternating sampling periods** where sampling takes place for two consecutive years (meant to be averaged) followed by a gap of up to three years before the next round of consecutive surveys. The length of the gap may be adjusted based on monitoring budget and risk levels, for example, to be shorter at particularly vulnerable sites with more variable and higher-risk management issues and longer at less vulnerable or variable sites. Sampling was scheduled in the same season for each site to minimize the influence of seasonal variation on statistical power to detect change and align with historical sampling practices and maintain long-term time series (Howe et al. 2023). When implemented in practice through a rotating sampling schedule, this typically involves intensive monitoring at one sentinel site each year and returning to each park every 2 to 3 years on average, though some are revisited on longer time cycles of up to 4-5 years.

Parks Victoria also pursued **power analyses** on the overall sampling design and, in some cases, on specific sampling methods and datasets (e.g., BRUVS data) to explore whether an unbalanced sampling design could maximize power to detect change while also retaining sufficient power to detect an 'MPA effect' where predicted based on comparisons of data inside and outside the MPAs (Howe et al. 2023).

Based on evaluation questions and guidelines, the recommended alternating sampling approach, the outcomes of power analyses, and promising results from pilot testing of emerging technologies, revisions were made to the suite of monitoring methods and tools being applied across MPAs and individual sampling designs were crafted for each MPA site that would go on to contribute data to the new statewide monitoring, evaluation, and reporting program for Victoria's MPAs (Howe et al. 2023). The **suite of methods** carried forward for application across sentinel sites included (Howe et al. 2023):

- **Shallow reef dive surveys** using a revised Reef Life Survey protocol, focused on fish, mobile invertebrates, and macroalgae – considered the longest-running and best source of ecological data in terms of the level of detail it can provide for the cost,
- **BRUVS**, focused on fish and invertebrates in deeper algal-dominated reefs less suitable for Reef Life Surveys and also particularly useful for collecting concurrent data for inside-outside comparisons, but limited in the amount of data it can collect due to limited soak times,
- **Towed video**, focused on monitoring larger swaths of habitat forming macroalgae,
- **Autonomous underwater vehicles (AUVs)**, focused on paired monitoring of oceanographic and ecological data to link physical and biological processes in MPAs,
- **Unmanned aerial vehicles (drones)** to largely replace prior visual census monitoring methods for intertidal areas to obtain greater spatial coverage and enable land-scape scale habitat classification. However, it has been recommended that visual census methods should be continued for targeted intertidal species that cannot be effectively be monitored from the air (e.g., mobile invertebrates targeted for harvesting).
- **Fishery-independent lobster trap surveys** using a balanced design sampling inside and outside of MPAs to more effectively monitor a keystone reef species that is targeted for harvesting and expected to benefit from protections within MPAs.

Several other changes were recommended in monitoring programs related to key indicators specific to each MPA, and the results from these programs are intended to be drawn into final reports on monitoring programs for each MPA alongside statewide monitoring program results for those sentinel MPAs in which such monitoring is carried out (Howe et al. 2023). For example, once development of the protocol is complete, the objective is for managers to eventually carry out the **Rapid Health Assessment** across all MPAs each year to provide information on bigger-picture status and trends across the MPAN to complement the more detailed information emerging from statewide monitoring at sentinel sites. However, due to insufficient capacity, efforts are currently being limited to select areas with higher visitation or easier access. It is likely that not all parks will be monitored on a regular basis, particularly those that are in more remote and rugged areas that are difficult to access.

Alongside redesign of data collection activities, the monitoring review process also recommended updates to **data management** activities. Prior data management practices relying on separate relational databases for different monitoring programs that were not being maintained and ultimately discontinued. For **management data**, Parks Victoria uses the statewide Environmental Information System (EIS) to collect and report on information such as pest assessment and control activities and habitat management actions. For **environmental and ecological data**, Parks Victoria initially transitioned to a centralized internal PostgreSQL database linked with custom interface QCore software for improved consolidation, quality control, access, and visualization, and interpretation of MPA monitoring data from multiple environmental monitoring programs (Emmunds and Flynn 2022). However, challenges in developing and maintaining internal databases and systems have rendered this system defunct, and Parka Victoria is currently relying on external partners to host much of the data collected as part of its marine programs. As a result, Parks Victoria is considering moving to a model where raw data is hosted in well-supported external databases to ensure it is readily accessible and easily visualized for use in evidence-based management (Howe et al. 2023).

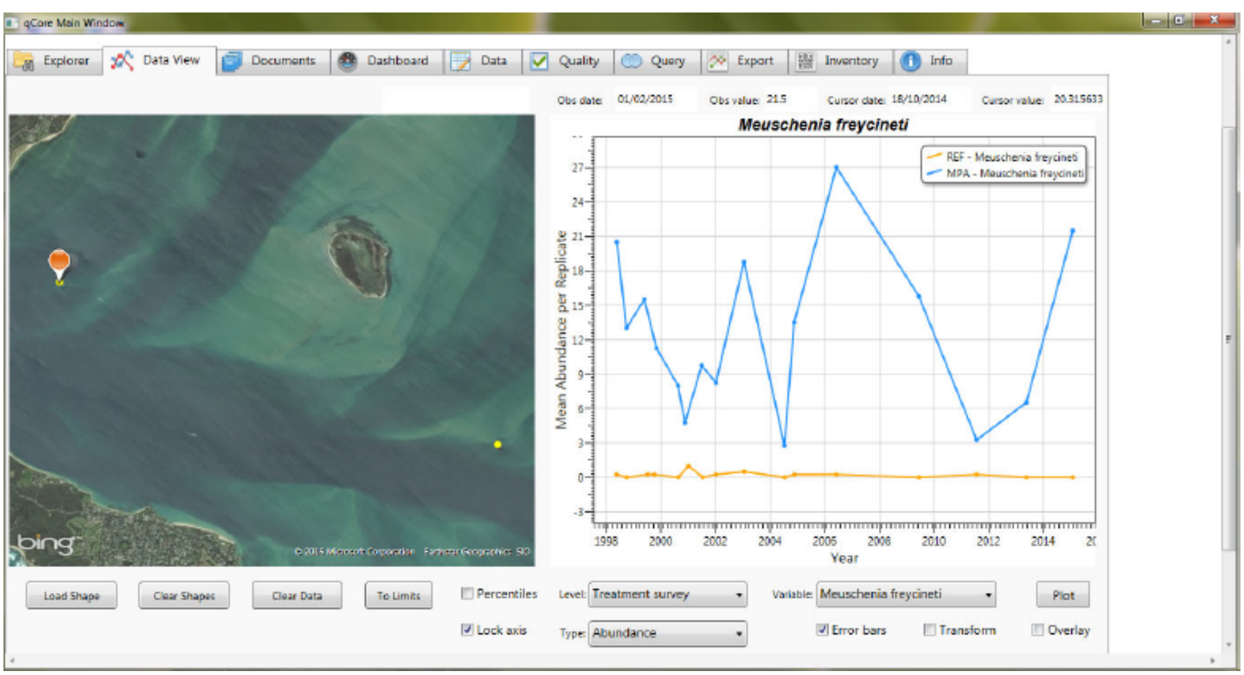


Figure 14: View of the main user interface for the now-defunct QCore database interfacing software demonstrating how such an integrated platform can be used to quickly access, explore, and visualize MPA monitoring data. Because of challenges developing and maintaining custom internal software solutions, there is growing interest in transitioning to the use of well-supported external databases that can offer similar benefits. Reproduced from Howe et al. 2023.

Updates have also been made to the external data management process for the Sea Search citizen science monitoring program to facilitate data collection and direct data entry on mobile devices and facilitate access to the data by both program volunteers and park staff. Finally, some types of monitoring data of broader interest are also housed in open data networks and portals such as the Australian Ocean Data Network (AODN) (e.g., underwater visual census data, oceanographic data) and GlobalArchive (e.g., BRUVS and towed video data) as well as research partner systems and databases.

Reporting

The updated monitoring program has been successfully implemented in all five sentinel sites, with reports for some sites already published as part of the Parks Victoria Technical Series. These reports emphasize **visual reporting**, using graphical conceptual models of key assets and threats in each MPA, as well as a traffic light system associated with control charts for reporting on status and trends in indicators and interactions between value and threat indicators. These monitoring program reports have carried forward the control chart element of the prior report card project and plot trends and established control limits and control charts for specific indicators and the methods used to measure them, with a present focus on control charts for intertidal and subtidal reefs (Howe et al. 2023, see bottom panel in Figure 18). Reports also include data on trends in key environmental drivers, such as sea surface temperature (SST), which provide important context for the interpretation of trends in other monitored values. There is also an intent to develop additional integrated habitat and potentially site-level control charts and draw in the results of other monitoring programs into MPA condition reports in the future (Howe et al. 2023).

Detailed technical reports also continue to be accompanied by summary reporting using templates for summarizing results of research and monitoring projects and programs for a broader audience, focusing on key objectives, outcomes, and management implications. Improved reporting and communication of MER program outputs are viewed as essential for **supporting continued integration of these outputs** into internal and external evaluation and decision-making processes, including: (1) the planned periodic review of CAPs at 5-year intervals, (2) the review and revision of park-specific management plans for implementing CAPs at 10-year intervals, and (3) the statewide State of Parks evaluation and broader Victorian State of Environment reports (Howe et al. 2023). In reciprocal fashion, these evaluation programs and processes as well as ongoing communication and relationships with communities, partners, and experts, are also expected to identify new issues and threats that may warrant further adjustments to monitoring for surveillance of emerging concerns (Howe et al. 2023).

Improvements & Future Opportunities

The adaptive management approach adopted by Parks Victoria has enabled the delivery of an extensive MER program across its statewide MPAN that has enabled ongoing learning and adjustment to keep pace with evolving global best practice. The 20th anniversary of establishment of the MPAN coincided with the completion of the first fill round of monitoring surveys as part of the updated monitoring program, providing the next opportunity to take stock of further lessons learned and consider **opportunities for future improvements** as the environmental, social, technological, and management contexts of the region continues to evolve (Howe et al. 2023).

One of the principal gaps in Victoria's past and contemporary MPA monitoring programs continues to be a lack of representation of the knowledge, values, and participation of Australia's **Indigenous Traditional Owners**. Ongoing efforts by Traditional Owners to expand the recognition of their rights and title have included the establishment of a growing number of Indigenous Protected Areas (IPAs) across terrestrial Country or marine Sea Country sites, including in the state of Victoria, and participation in patrolling, monitoring, and managing these sites through Indigenous-led ranger programs (Gould et al. 2021). Many successful examples of cross-cultural marine monitoring programs incorporating both traditional and modern approaches are now emerging across Australia that may offer helpful insights for other communities, states, and regions interested in building relationships and co-developing marine monitoring activities with Traditional Owners that can be streamlined into existing monitoring, evaluation, and reporting programs using traditional and novel monitoring techniques and technologies (e.g., Depczynski et al. 2019, Davies et al. 2020, Gould et al. 2021). The Australian Institute of Marine Science has also assembled helpful lessons learned on 'closing the circle' by returning knowledge to the country through sharing monitoring results across generations of Traditional Owners using a wide range of accessible and culturally appropriate communications strategies, each of which have their own pros and cons (AIMS 2021).

Victoria Parks is also just beginning to pursue statewide evaluation of key indicators across its MPAN. For example, a recent study using data collected through multiple sources and methods, including long-term monitoring programs, employed state of the art modelling and machine learning approaches to carry out a **state network-scale evaluation** of the representation of habitats and environmental conditions and how they have changed through time as well as evaluating the connectedness (Young et al. 2022). Key findings from this effort included:

1) That existing MPAs represented all key habitat types found within their biounits but that some types were over- (rocky reefs) or under- (soft sediment) represented,
2) That a diversity of oceanographic conditions are generally well represented, but are better represented in larger MPAs
3) Connectivity modelling showing strong geographic patterns of dispersal within the state with more self-recruitment (i.e., less connectivity) in the central part of the state,
4) Identification of positive environmental drivers of species abundance and diversity that can be used to inform targeted management,

5) Determination that BRUVS and habitat mapping data allowed for effective species distribution modelling at the state scale and performed better at a whole-assemblage scale than a species scale, and
6) Provided a first network-scale assessment of MPA effectiveness, finding that fish species richness was higher inside than outside MPAs and identifying specific correlates of MPA effect size, including MPA size, the presence of depth and habitat barriers to connectivity, and distance from ports and human settlements.

Although this study was carried out as a stand-alone research project, it provides a template that could be followed for regular operational network-scale evaluations meant to inform adaptive management.

Other efforts to develop **national network-scale evaluation frameworks** for MPAs in Australia as a whole, including proposed aggregate indicators such as the trends in total number, area, protection levels, habitat representation, and connectivity across the network, may inform the development of further indicators of effectiveness at regional and state scales to inform network-scale management strategies (Roberts et al. 2018, 2021).

Much of the extensive body of work being carried out at the scale of Australia's national MPAN for the National Environmental Science Program's Marine Biodiversity Hub promises to generate a wealth of insights that could inform future revisions to state MPA monitoring, evaluation, and reporting programs (Hayes et al. 2021). For example, detailed high-resolution maps of **pressures** produced for a wide range of pressures in the national MPAN's South-East Region which encompasses the state of Victoria (Hayes et al. 2021), and evaluation of the ability to monitor these pressures using remote sensing (Sagar et al. 2020), could be used to inform future monitoring design for threats at a state scale and form the foundation for the development of additional site and network-scale monitoring and evaluation activities geared at tracking the scale and impacts of **cumulative effects** on marine ecosystems.

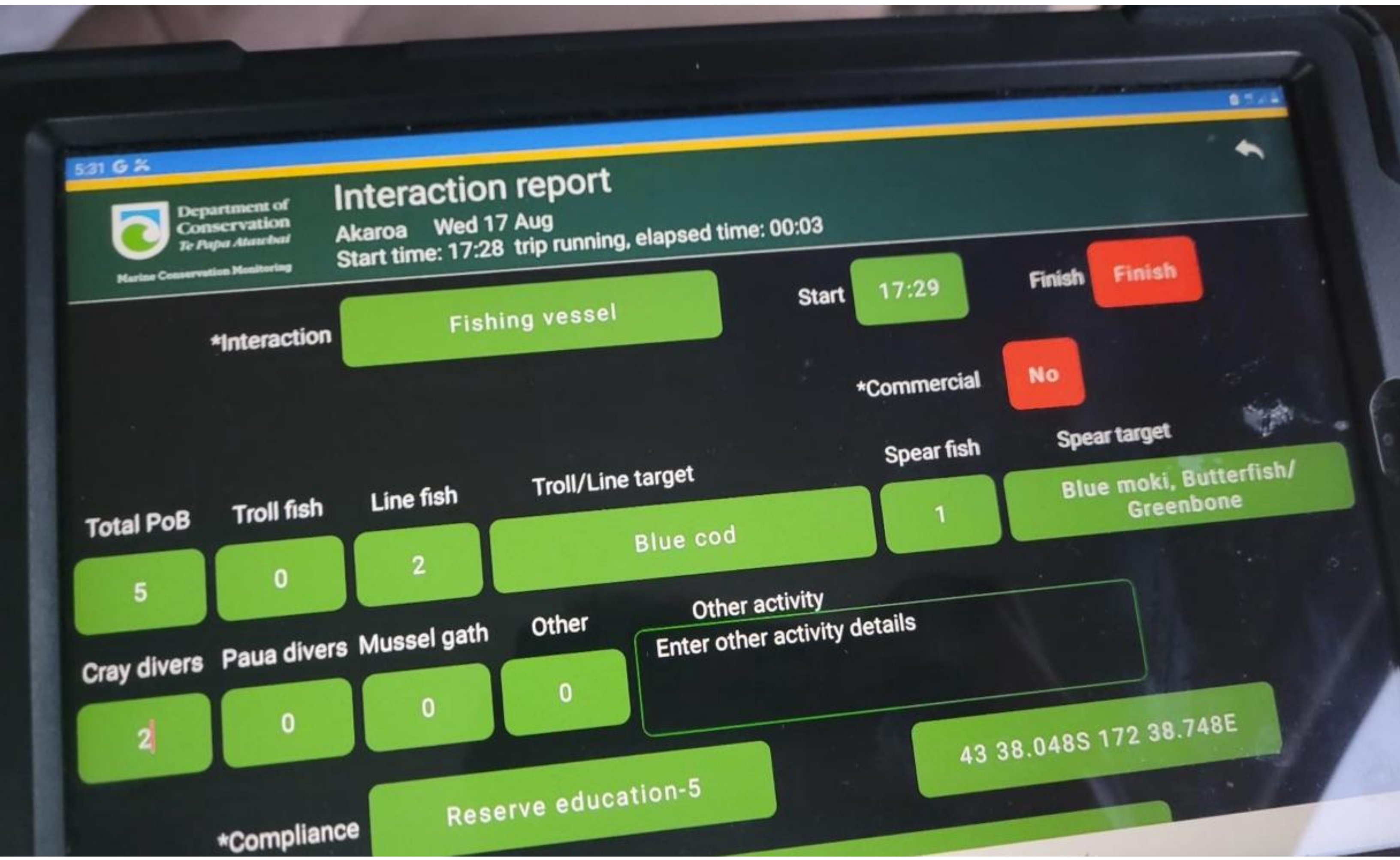
Region-wide maps of environmental conditions and stressors can in turn serve as inputs to ecological models useful for monitoring design and evaluation. For example, biophysical **connectivity** modelling for key species at a national scale suggests that the marine bioregions adjacent to the state of Victoria have among the lowest connectivity to other regions of any part of the coast, and was lowest in the more sheltered central region of Victoria's coast, with the latter finding corroborated by statewide assessment of larval recruitment and connectivity (Young et al. 2022). This suggests that many larvae from other regions did not reach protected reefs in this area and that the natural rescue potential in the event of population declines at these reefs is low and that more intensive local monitoring and management may be warranted for these species (Roberts et al. 2021). Similarly, national-scale **climate change** analyses suggest significant temperature trends at some sites along the Victorian coast, where more deliberate monitoring and management planning for climate impacts may also be warranted (Tan and Fisher 2022).

Finally, National scale research and **pilot testing of emerging monitoring technologies** could also help to pave the way for adoption at state scales. These efforts include pilot testing of passive acoustic monitoring using underwater recorders, aerial drones operated beyond visual line of sight, and autonomous sailing surface drones known as 'bluebottles' being used for both environmental and compliance monitoring (Gueho 2023). These efforts have spurred similar pilot investigations in the State of Victoria's MPAN through a partnership between Parks Victoria and academic researchers to inform improvements to Victoria's subtidal monitoring program (Young et al. 2022). Given the potential synergies between these parallel efforts, better coordination is needed among states and between states and national MPA MER programs to provide a more detailed and holistic picture of MPA status, trends, and performance at a national scale that includes protected areas in both state and Commonwealth waters.

Through their ongoing commitment to adaptive management of both monitoring and management activities across the state MPA system, Parks Victoria and its partners in monitoring are well positioned to take advantage of the latest emerging knowledge and best practices to continually improve regional MPA monitoring programs and management outcomes.

Case Study 5:

Aotearoa New Zealand MPAN Marine Monitoring Framework



Human interactions app to be used by rangers, Credit: Monique Ladds presentation at IMPAC 5 conference

Key Lessons from this Case Study

Partnerships with Indigenous Peoples are Essential
Aotearoa New Zealand is taking steps to establish partnership with Indigenous Peoples as part of the MPAN monitoring process, although these remain at relatively early stages. The 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.

Standardized, Broad Scale Monitoring Can be Complemented With Site-Specific Monitoring
The Marine Monitoring and Reporting Framework 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.

Monitoring Frameworks Can Enable Standardized Analysis and Reporting
Within each of the Marine Monitoring and Reporting Framework's 10 themes, guidance is provided about expected analyses and templates for expected results and reporting formats. By including this guidance, monitoring plans for individual MPAs and MPANs can be developed with clear expectations and standardization of reporting across partners, sites, regions, and years (e.g., standardized reporting metrics and plots for each analysis and monitoring question).

Introduction

Marine habitats in Aotearoa New Zealand include sheltered inlets, fjords, estuaries, seagrass beds, kelp forests, shellfish beds, sandy coasts, coasts and reefs, and open ocean. The Marine Reserves Act (1971) provides a legislative basis for the creation of MPAs in Aotearoa New Zealand, resulting in the establishment of Aotearoa New Zealand's first no-take marine reserve in 1975. To date, Aotearoa New Zealand has 44 marine reserves, covering 17,700 km^2. There are currently three types of marine reserves: no-take marine reserves (Type 1 MPAs); other protected and managed areas that meet the protection standard (Type 2 MPAs); and other forms of protection that do not achieve the standard (e.g., cable protection).

In 2005, Aotearoa New Zealand set in motion planning for MPANs that protect representative habitats of marine biodiversity (Marine Protected Areas Policy and Implementation Plan, MPAPIP 2005). The MPAPIP laid out principles for designing the network and for guiding the planning and management process (Table 26), however, it is notable that monitoring and evaluation were only mentioned for development at a later stage. To further the MPAN planning process, 14 biogeographic marine regions were identified as a basis for where to implement MPANs (Department of Conservation and Ministry of Fisheries New Zealand 2008; classification of these marine regions were reviewed more recently in Rowden et al. 2018). The guiding document also prescribed a Marine Protection Planning Forum (MPPF) process to be applied within each region as an inclusive community-based process for delineating MPANs. In 2019, a Principles for Network Design document was released and included potential MPAN design principles of representativity, replication, adequacy, viability and connectivity (Department of Conservation, 2019). This document also noted some challenges for establishing quantitative targets for each design principle, including limited information for certain habitats and species. Finally in 2020, goals for establishing MPANs were renewed with the New Zealand Biodiversity Strategy, which state:

> *By 2035 an effective network of marine protected areas and other tools, including marine and coastal ecosystems of high biodiversity value is established and is meeting the agreed protection standard.*

Table 26: Implementation principles for the establishment of a network of representative MPAs in New Zealand (Marine Protected Areas Policy and Implementation Plan 2005).

Principles	
Network Design Principles	1. The MPA network will protect examples of the full range of natural marine habitats and ecosystems
	2. MPAs should be designated based on a consistent approach to classification of habitats and ecosystems
	3. The MPA network should be viable
	4. National priorities for additions to the MPA network will be developed, and reviewed on an annual basis
	5. An evaluation programme will be undertaken
	6. A monitoring programme will be undertaken
Planning Principles	1. Every MPA should be designated on the basis that it is representative of one or more habitats or ecosystems, and in a manner consistent with the national network priorities and the MPA implementing principles
	2. The management tool(s) used at a site must be sufficient to meet the protection standard
	3. The special relationship between the Crown and Maori will be provided for, including kaitiakitanga, customary use and mätauranga Maori

Principles	
	4. MPA establishment will be undertaken in a transparent, participatory, and timely manner
	5. Adverse impacts on existing users of the marine environment should be minimized in establishing MPAs
	6. The management tools used to establish MPAs should be consistent and secure in the long term, subject to any necessary changes to allow them to better achieve the MPA Policy objective, taking into account natural dynamics
	7. Best available information will be taken into account in decision-making
	8. Decision-making on management actions will be guided by a precautionary approach
	9. The MPA management regime must be enforceable
	10. MPA research will be effectively planned and co-ordinated

A few additional resources related to the process for establishing MPAs and MPANs are worth noting. Based on a review of two regions that engaged in processes for developing potential MPAs, an Auditor General report in 2019 found that the MPPF process can be fraught with challenges and tensions and has taken a long time to implement. In the Kaikōura coast region, an alternative community-based approach was led by Te Korowai o Te Tai ō Marokura, the Kaikōura Coastal Marine Guardians (Te Korowai) and resulted in a series of marine management measures. In Southern South Island coastal bioregion, a MPPF process, known as the South-East Marine Protection Forum (SEMPF), included four years of Indigenous and community consultations. This ongoing process most recently resulted in a series of recommendations for the government (see also Watson et al. 2021). Currently, a third process is underway to explore the potential for establishing a MPAN in the northern portion of the North Island.

Biodiversity Monitoring

Monitoring of MPAs has been "inconsistent, with different approaches and standards being applied across the network" (MMRF 2022). This has made any regional or national evaluations difficult. While broader than only marine monitoring, Aotearoa New Zealand has taken several steps towards towards more consistency through a series of reports:

- The Department of Conservation's Biodiversity Monitoring and Reporting System is intended to provide consistent and comprehensive information about biodiversity across New Zealand's conservation land and oceans. As shown in Figure ##, the reporting system consists of three tiers: Tier 1 is broadscale monitoring, Tier 2 is monitoring of managed places (e.g., MPAs), and Tier 3 is place-based research. Evaluation of performance measures is intended to include a variety of indicators related to biodiversity outcomes.

- The Biodiversity Strategy (2020) is a strategic framework for the protection, restoration and sustainable use of biodiversity across all Aotearoa New Zealand. Although the Biodiversity Strategy did not go into depth about monitoring, it provided clear indications about the importance of independent and transparent monitoring for evaluating progress towards protecting biodiversity. The Strategy also established 5-year implementation cycles that involve monitoring to feed into decision-making for future implementation cycles.

- The Biodiversity Strategy Implementation Plan (2022) established a pathway for achieving the outcomes of the Biodiversity Strategy over the next 30 years. As part of an adaptive approach to implementation, monitoring is envisioned as a key part of 5-year reviews that evaluate progress towards goals and outcomes, reassess priorities, and develop new actions. This monitoring will necessarily require "improved systems for knowledge, science, data and innovation". Indigenous partners (Mātauranga Māori) are also envisioned as integral for biodiversity research and management.

- The Marine Monitoring and Reporting Framework (2022) is a national marine monitoring system that focuses on MPA (marine reserve) monitoring. The MMRF constitutes Tier 2 monitoring for marine reserves (monitoring managed places) under DOC's Biodiversity Monitoring and Reporting System (Figure 15) and will also feed into Tier 1 monitoring, which looks at national trends. Further details about the MMRF are summarized in the following section.

- Additional reports are also available through the Marine Protected Areas Research Programme website and the Marine Inventory and Monitoring website.

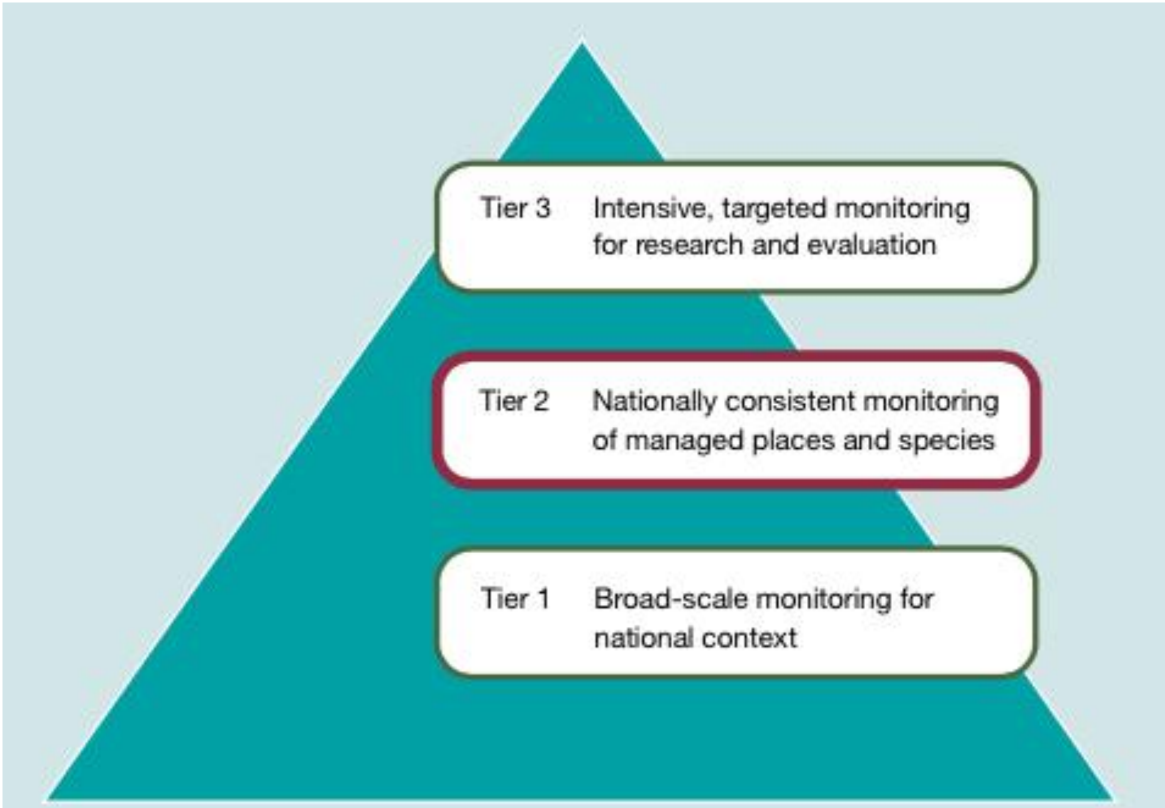


Figure 15: Tiers of the Department of Conservation's biodiversity monitoring and reporting system (figure from Department of Conservation 2022).

Marine Monitoring and Reporting Framework

Work towards standardization of marine monitoring and creation of the MMRF was initiated in 2018 with the hiring of a full time staff on this file. The approach taken by the Department of Conservation was to create a framework that enabled standardized monitoring but also allowed flexibility for site-specific needs (Figure 16). As each MPA has unique biological and habitat features, they also are interconnected with communities and Indigenous peoples who will have interests in any monitoring that takes place.

> *"The MMRF has taken DOC's [Department of Conservation] standardised monitoring framework and adapted it to the marine environment as a suggestion of what should be monitored nationally. It does not make any assumptions about what is to be monitored at place. Instead, using guidance from this document, marine reserve monitoring plans will be co-developed and co-implemented with whānau, hapū, iwi and communities." (MMRF 2022)*

The proposed approach in the MMRF includes potential for site-specific monitoring and co-design and co-implementation with tangata whenua (Māori term for "people of the land") where there is interest to do so.

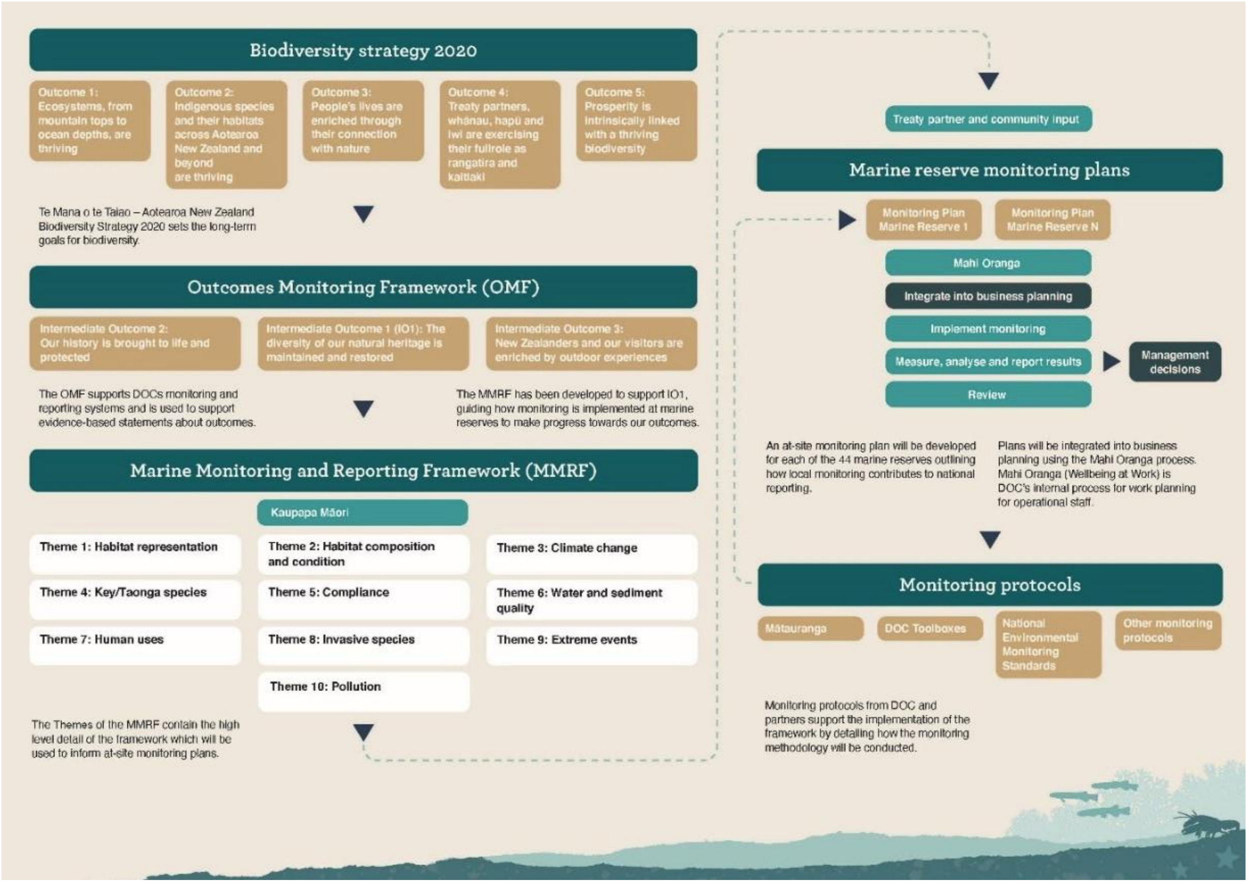


Figure 16: Model of the relationship between elements of the Marine Monitoring and Reporting Framework (Department of Conservation 2022b).

The overarching purpose of the MMRF is to *"provide a national marine monitoring and reporting framework that will enable the evaluation of the status and trends of marine reserve ecological integrity"* (Department of Conservation 2022b). As stated in the MMRF, marine monitoring is intended to meet numerous needs (Department of Conservation 2022b), including:

- Inform, educate, and involve people
- Assess existing reserves
- Support establishment of an effective network of MPAs
- Meet domestic and international reporting requirements
- Make informed management decisions

It is notable that development of the MMRF was largely influenced by the Integrated Monitoring Framework for the Great Barrier Reef (Hedge et al. 2013). In particular, the relationship between management objectives and monitoring objectives was influential. The management objectives help to establish relevant research questions and the types of monitoring that will be needed to answer those questions.

The framework includes 10 thematic areas (Table 27) that are intended to enable measurement towards the objectives of the Biodiversity Strategy (Department of Conservation 2020). These 10 themes were developed within the following guiding principles:

- Engaging tangata Māori
- Using standardised methods
- Working together
- Drawing on and contributing to existing monitoring programmes
- Involving the community and/or citizen science

While there is broad inclusion of human dimensions within the MMRF and strong support for working with Indigenous people, the framework does not provide specific guidance on how to integrate western and Indigenous forms of science and knowledge. Through discussion with DOC staff, however, that such integrative processes do not necessarily need to be written down. As Māori will be involved directly with knowledge integration, they will be able to guide the processes based on local interests.

Table 27: 10 themes in the Marine Monitoring and Reporting Framework (2022).

Theme 1 – Identify the proportion of ecosystems protected
Theme 2 – Determine changes in habitat composition and condition
Theme 3 – Define and track climate change indicators
Theme 4 – Describe the abundance and demography of key species
Theme 5 – Determine the rates of compliance
Theme 6 – Evaluate environmental water quality indicators
Theme 7 – Understand human uses of and relationships with marine reserves
Theme 8 – Detect non-indigenous species
Theme 9 – Determine the effects of extreme events
Theme 10 – Understand the impact of pollution

Within the MMRF, each theme (Table 2) is discussed in detail according to a number of key topics. These topics include:

- Background and objectives
- Existing monitoring programmes
- Sampling design (including selection of indicators and monitoring programmes)
- Monitoring protocols
- Data management (including quality control, quality assurance, and data storage)

- Data analysis (including methods for data preparation/processing, data exploration, assumption testing, hypothesis testing, and data visualization)
- Reporting and communication
- Reviewing and auditing

Partnerships and Community Engagement

Owing to the orientation of the Marine Reserves Act (1971), there is a large emphasis on research in Aotearoa New Zealand MPAs. As such, partnerships with university researchers is common to the extent that many MPAs and marine reserves have researchers associated with them. The DOC provides the researchers with toolboxes that include standardized protocols for monitoring. These partnerships provide student researchers with hands-on experience while collecting important data. Other important partnerships are with regional councils. The DOC maintains relationships with the regional councils through resource and knowledge sharing (e.g., related to water quality monitoring).

In 2023 the DOC is piloting the use of a custom built app that will be used by rangers in 26 marine reserves. When the rangers do patrols, they will enter information about their interactions with people. In some instances, these interactions may entail education related to conservation or specific actions taken in relation to compliance and enforcement. The intent of this data collection is to be able to fill a gap in understanding how people are interacting within MPAs, which will in turn help with future management and enforcement.

Another technology being employed to engage communities and the wider public is a citizen science program called Spyfish Aoterora. Through the Zooniverse platform, volunteers are able to count and identify fish species from underwater images. The uptake of this program has been very successful. Approximately 3,000 people signed up over an 18 month period and counted an estimated 20,000 fish. There are plans to build an education tool based on Spyfish Aoterora, where students will learn more about monitoring techniques as well as the design of monitoring and how marine learning can help to address conservation problems.

Part 2: Literature and Expert Insights into Best Practices for Marine Protected Area Network Monitoring

Blacksmith Diver, Point Lobos, Credit: Miranda Haggerty

This section begins by reviewing insights and lessons about early design and implementation of MPAN monitoring, which leads into detailed insights and considerations about key indicators for MPAN monitoring. Next, we review best practices for data collection and emphasize some technologies and approaches that may be particularly relevant for the context of the NSB. We also review important considerations for data management, both from the perspective of a large group of diverse marine environment sites and in consideration of Indigenous partners' potential interests in data sovereignty. Then we discuss analyses that have been used specifically for MPAN monitoring, including ways of assessing changes in characteristics such as habitat representation and connectivity. Finally, we review best practices for reporting and communications - including the importance of managing partners' and the public's expectations - and how analyses and reporting may be used to inform future decision-making.

2.1 Early Stages of MPAN Formation and Monitoring Design

Both the published literature and insights from case study interviews suggest that MPAN monitoring and evaluation are most effective when planning is initiated and supported by strong policy and funding. Establishing provisions for MPAN monitoring within legislation can be critical for ensuring that governments commit long-term funding that is needed for implementing an effective monitoring strategy. Securing consistent, reliable funding is essential to make sure that (1) there are not any gaps in data collection (e.g., missing years/months), and (2) there is a plan in place to collect data at regular intervals at the same sites. In the recent California MPAN 10 year review, partners noted that it was critical that they have consistent datasets that were collected at the same sites regularly. For instance, if monitoring is conducted at a site only once every three years, after 10 years there will only be three data points to work with. That may not be enough data to show a trend with any sort of confidence. Thus, when designing a monitoring plan, decisions about intervals for data collection at individual sites will be very important. There are trade-offs to be made between monitoring at a larger number of sites versus monitoring at fewer sites but doing so more frequently.

Strong coordination among partners is also important for governance of MPAN monitoring. Research and evaluation has repeatedly demonstrated that inclusion of all MPAN partners and other key actors is essential for sustained, long-term success (Alexander et al. 2016; Hall-Arber et al. 2021). Muhl et al. (2022) have shown how identification and development of indicators is a very subjective process and inherently involves power dynamics. Attention to these dynamics and relationships among MPAN partners is critical for adoption of monitoring plans and long-term success. In most case studies for this report (Part 1), the organizational structure for monitoring activities was developed after delineation and implementation of MPAs. One exception was New Zealand, where a monitoring framework has been developed and released prior to establishment of the entire MPAN. 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 of each partner.

Strong participatory processes also help to facilitate the development of an overarching evaluation framework that both addresses network-level questions and allows for site-level needs and questions. In addition to questions about representativeness, connectivity, and other design features (Burt et al. 2014), the California decadal review identified a series of additional evaluation questions that demonstrate the types of large-scale, network-level issues that will be present for a MPAN (see Appendix 1 and 2 in Hall-Arber et al. 2021). At the same time, individual sites within a MPAN - which could be managed by different jurisdictional authorities, have varying levels of protections, and represent different habitats and species - will have local-level questions that also need to be addressed through monitoring. For instance, a site that was protected due to the presence of a species that is important for fisheries or that has a restricted geographical range may require types of monitoring that are not required at other sites.

2.2 Baseline Monitoring

Globally, most MPANs have not collected baseline data prior to implementation of the entire network. What has been collected tends to be site-specific or related to stock assessments, for example, data related to known or suspected species and habitats or compilation of fisheries data. While these types of data are instrumental for delineating boundaries and rules for protected areas, the literature and case studies did not reveal any systematic, network-wide approaches to collection of baseline data. For instance, in California the MPAN was designed and implemented several years before a monitoring plan was formally put in place, despite advocacy from experts for the early development of a monitoring plan. 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 (see California case study for further details). As the network was implemented in each region along the coast, baseline data were collected in the first year or so following implementation. Based on this experience, a key consideration for developing and implementing a new MPAN is to reflect on how data collected at different sites, different years, and for sometimes different purposes (e.g., existing MPAs that already have time series data, versus new MPAs with little or no data) may be aligned for contribution to baseline and long-term monitoring efforts.

Collection of baseline data requires many of the same considerations as long-term monitoring and often shapes planning of ongoing monitoring programs in diverse ways. For instance, application of appropriate indicators and the selection of data collection techniques and technologies is important for both baseline data and long-term data, while the ability to collect baseline data prior to MPAN implementation has a strong influence on the type and scientific rigor of study designs that can be used to evaluate network effectiveness. For these reasons, baseline monitoring is discussed throughout many of the sections that follow.

2.3 Categories of MPAN Monitoring

Indicators are qualitative or quantitative biological, chemical, physical, social, cultural, and/or economic measurements that act as proxies for attributes of socio-ecological systems. When measured repeatedly as part of broader, rigorously designed monitoring programs, indicators provide a practical means to assess changes in attributes of the socio-ecological system over time relative to management objectives. This information can help to assess risks, predict future change, and inform adjustments in both monitoring and management practices through adaptive management (Longo et al 2015; Tony 2020).

In the context of MPAs as a form of management intervention, **management goals and objectives** provide the basis for a monitoring framework intended to assess overall MPA performance. Although management goals and objectives can vary widely across local contexts, many can be linked back to the six qualitative elements of Aichi Target 11, which calls in part for coastal and marine areas to be conserved through systems of protected areas that (1) encompass areas of importance for biodiversity, conservation, and ecosystem services, (2) are ecologically representative, (3) are ecologically connected, (4) are equitably managed, (5) are effectively managed, and (6) are integrated into the wider land and seascape (CBD 2011, Dunham et al 2020, Meehan et al. 2020).

Within the context of these goals and objectives, MPA monitoring frameworks generally encompass four categories of monitoring and related indicators (Dunham et al. 2020):

- **Human Pressure Monitoring** (also referred to as compliance monitoring): Given that the primary purpose of an MPA is to reduce human pressures to allow for ecosystem recovery, monitoring human activities and pressures is fundamental for understanding whether the intended protections are being realized or whether MPAs are operating as ‘paper parks’. Where protections are not being realized, changes to management strategies and actions may be needed before the desired ecological outcomes can be achieved. This type of monitoring may assess social and governance indicators such as compliance for restricted activities, changes in unrestricted activities, or emerging activities and associated pressures.
- **MPA Performance Monitoring**: Monitoring programs and indicators related to management interventions, including protection and zoning in an MPA, should include and also extend beyond status and trends monitoring to include effectiveness or

performance monitoring that aims to understand whether MPAs are ‘working’, either individually or collectively across networks, to mitigate key pressures and achieve their management goals and objectives (Reynolds et al. 2016, Hayes et al. 2019, Dunham et al 2020). This category of monitoring usually measures MPA-specific indicators of socio-ecological state, function, and/or services inside and outside of MPAs to detect MPA effects over time. Importantly, achieving MPA objectives does not always require improvements in performance indicators; at relatively undisturbed sites, ‘success’ may be defined as maintaining a baseline or slowing rates of decline (e.g., for biomass, body size, or abundance) compared to non-MPA sites (Dunham et al. 2020).

- **Reference Monitoring:** MPAs are valuable as reference areas for studying the effects of global and regional-scale pressures such as 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 these broader-scale pressures are not confounded by the effects of local human activities. Reference monitoring considers the differences between MPA and non-MPA sites (e.g., marine impacts in fished areas compared to no-take MPAs). For example, the biomass of exploited species in unfished no-take areas could be used as a proxy for unfished biomass to derive better empirical estimates of stock status (e.g., as for New Zealand lobster, Hanns et al. 2022).
- **Ambient Condition Monitoring:** Ambient condition monitoring, also known as surveillance monitoring, aims to capture knowledge and data about broader-scale trends or phenomena relating to ocean health such as recurring regional climate patterns, long-term climate-change, species status or community structure for the broader marine region and may occur both outside and inside MPAs, but without explicit relationship to MPA status or boundaries. This information is important in the larger context of ecosystem-based management, but is also relevant to evaluating MPA effectiveness by (1) capturing information on factors thought to influence MPA outcomes but whose relationships to historical or emerging human pressures are not well understood to inform management and prompt targeted research to elucidate these relationships where needed (Shepherd et al. 2015), and (2) serve as covariates in data analyses to help disentangle the causal drivers of MPA outcomes to ensure that observed effects can be attributed to protections rather than broader environmental change.

Potential indicators relevant to each of these interrelated monitoring categories are numerous and diverse, but can generally be related to four broad domains of **socio-ecological systems:**

environmental, ecological, socio-economic, and **governance** (Hall-Arber et al. 2021). Each of these dimensions encompasses multiple categories of related indicators and some indicators are also relevant across multiple dimensions. Notably, prior global reviews of indicators used in MPA and MPAN evaluation have revealed significant gaps in both indicators and approaches used for MPA and MPAN evaluation, showing that:

- Environmental and ecological indicators are overrepresented in evaluations relative to other types of indicators (Meehan et al. 2020), with most evaluations in temperate regions relying solely on ecological indicators (67%), with a smaller subset relying solely on social indicators (12%) (O'Leary et al 2021),
- Few evaluations of indicators have been carried out explicitly at network scales, with a disproportionate number of evaluations focused on single MPAs (60%) as opposed to multiple individual MPAs (33%), or MPANs (7%) (O'Leary et al 2021).
- Few evaluations move beyond simple reporting of observed effects for focal indicators, with a disproportionate number of evaluations in temperate regions based on principal evaluation of effects (70%), whereas far fewer sought to establish the causes of these effects (30%), and virtually none (0.3%) evaluated the broader ecological, social, and/or economic benefits of these effects (O'Leary et al 2021).

The nature of MPANs also implies the need for consideration of monitoring indicators capturing insights across multiple spatial and temporal scales. Some indicators represent **site-scale indicators** meant to track status, trends, and effectiveness at individual sites, which are necessary to inform site-specific monitoring and management plans and adjustments for individual MPAs. Other indicators are inherently **network-scale indicators** that measure characteristics of the network as a whole, and are typically derived from analyses that pool and synthesize site-scale metrics to understand their emergent properties at the network scale. In each case, the end goal is for indicators to provide insights allowing managers to assess whether the performance of the whole MPAN is greater than the sum of its individual MPA parts (Grorud-Colvert et al 2014, Balbar et al. 2020). Such network-scale indicators include many core design features of MPANs such as representation, replication, and connectivity. These design features are generally first assessed as part of the planning process for MPAN designation, however, there is also a need to continue evaluating the extent to which these design features are being achieved over time as environmental, ecological, social, and regulatory contexts shift and the individual and synergistic effects of management interventions such as protection and restoration begin to manifest (Peters et al. 2017, Balbar et al. 2020, Hopf et al. 2022b).

When thoughtfully designed within an **adaptive management** framework, the outputs of effectiveness monitoring for MPAs can help to accelerate learning about best management practices and directly inform decisions to implement more effective management alternatives (Reynolds et al. 2016, Hayes et al. 2019, Nickols et al. 2019,Tony et al. 2020).

2.4 MPAN Monitoring Indicators

This section synthesizes insights from recent experiences with indicator selection and validation for MPA and MPAN contexts. We present key indicators within four broad domains: environmental, ecological, social, and governance. While this synthesis should not be considered comprehensive, it reflects current understanding of best practices.

2.4.1 Environmental

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 variables, and others** (Erhman et al. 2022). Environmental indicators are typically not directly influenced by MPAs themselves, but provide context and play a role as influencing factors on outcomes through their influence on habitat suitability (e.g., through physiological constraints on ecological niches) and connectivity (e.g., though watershed inputs affecting water quality or current-driven dispersal of nutrients and organisms), which in turn affect representation and biodiversity across MPANs (Erhman et al. 2022). Some environmental indicators such as substrate type and composition also directly capture information on **non-biogenic habitats** inhabited by particular species, whereas biogenic habitat types are captured by ecological indicators (see next section).

Environmental variables are generally not included in lists of most commonly used or ‘leading indicators’ of MPAN performance. However, it is critical that these indicators representative of influencing factors are still carefully monitored alongside other types of indicators and controlled 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 (Hayes et al. 2019, Erhman et al. 2022). To this end, environmental indicators are often critical inputs for modelling and analysis of indicators in other dimensions, including primary production, dispersal, habitat suitability, population dynamics, and ecosystem processes, among others (Erhman et al. 2022).

Summary of Methods and Tools

These indicators are measured through a combination of in-situ sensors and instruments, physical sampling, and mapping using acoustic or remote sensing (Ehrman et al. 2022).

Table 28: Summary of key environmental indicators for MPAs and MPANs along with representative examples of associated parameters, which should not be considered comprehensive, and links to Aichi Target 11 elements.

<table>
<tr><th>Indicator Class</th><th>Representative Parameters</th><th>Value of Information</th><th>Key Methods and Considerations</th></tr>
<tr><td>Core Oceanographic Parameters</td><td>• Current velocities
• Temperature
• Salinity
• Dissolved oxygen (DO)
• Dissolved inorganic carbon (DIC)
• Nutrients (N/P)
• Turbidity
• Photosynthetically active radiation (PAR) / Primary Productivity</td><td rowspan="2">Information on both core oceanographic parameters and benthic structure capture essential information on where preferred environmental conditions for key species and key habitat features of interest may occur, provide insights into ecological processes and food webs, and provide information on environmental variability as a potential confounding factor influencing MPA outcomes.

These parameters are critical inputs for most modelling of physical processes, primary production, dispersal, habitat suitability, population dynamics, and ecosystem processes, among others.</td><td>Core oceanographic parameters are typically measured together using a single instrument or instrument array, and are measured across depth profiles to capture variation throughout the water column. Spatial and temporal resolution of monitoring is highly contextual and monitoring may take place at discrete sampling periods or continuously through the use of real-time monitoring instruments (e.g., data loggers, oceanographic buoys)</td></tr>
<tr><td>Benthic Structure</td><td>• Bathymetry
• Substrate type and composition
• Organic matter profile</td><td>Bathymetry and substrate type are typically measured using sounding lines or multi-beam sonar in a one-time baseline survey followed by repeat surveys on relevant timescales for the local context. They do not typically undergo rapid change, but may be more variable in areas subject to influence from terrestrial inputs, coastal change, and nearby human activities (e.g., dredging, anchoring). Organic matter profiles are monitored via sediment samples or cores.</td></tr>
<tr><td>Terrestrial Inputs</td><td>• Precipitation and discharge
• Freshwater inputs (stable isotope levels and ratios)
• Sediment inputs (turbidity)</td><td>Terrestrial inputs influence many core oceanographic and benthic features in ways that affect habitat suitability and productivity.</td><td>Sampling should occur alongside core oceanographic monitoring in areas near and offshore to river mouths to capture the range of influence of terrestrial inputs.</td></tr>
<tr><td>Coastal Change</td><td>• Coastal position
• Drivers of coastal change (wind, waves, sea level)</td><td>Captures the influence of natural (e.g., storms) and human (e.g., vessel wakes) influence on coastlines with implications for marine species in coastal MPAs.</td><td>Monitoring of coastal change should be repeated every 2-5 years and coupled with monitoring of the marine implications of that change in terms of benthic structure.</td></tr>
</table>

Sources: Meehan et al. 2020, Ehrman et al. 2022

2.4.2 Ecological

Ecological indicators relevant for MPA and MPAN encompass features at multiple scales of organization, including species and their populations, communities and their composition and interactions, and the emergent features of species and communities at network and regional ecosystem scales (Erhman et al. 2022). However, not all indicators are well-suited for detecting MPA effects. This section provides an overview of both the most commonly used or leading indicators, as well as the most reliable indicators for assessing MPA effects at each of these scales of organization from prior reviews of indicators relevant to MPA evaluation (these are distinguished and summarized in Table 29). This section also provides a very brief overview of tools and methods typically used to measure these indicators. Notably, the performance of many ecological indicators for detecting MPA effects are likely to be influenced by site and network contexts such as degree of ongoing fishing pressure outside the MPA, level of protection within the MPA, and MPA size, as well as interactions between size and age, and regional environmental variability across the network (Soykan and Lewison 2015, Ziegler et al. 2022). These contextual influencing factors should be carefully accounted for in the design of monitoring and analytical frameworks.

Species-Scale Indicators

Virtually all reviews of species-scale indicators relevant to MPA evaluation include individual species **spatial distribution, abundance, and population structure** as the most essential indicators of effects on species (Pelletier et al. 2005, Loh et al. 2019, Meehan et al. 2020, O'Leary et al. 2021), and these are also important constituents for deriving community-level indicators (Soycan and Lewison 2015). Most reviews of indicators also included some form of **species dispersal**, which is also important for informing connectivity indicators (Meehan et al. 2020, Balbar et al. 2020) as well as community spillover benefits for the fishing sector (Barcelo et al. 2021, Qu et al. 2021). A meta-analysis evaluating the ability of common community-level indicators and metrics for detecting differences in community structure inside and outside of MPAs indicates that species-specific **population size distribution** and **population density by stage** (i.e., density by age, size, or maturity class) for a given species perform much better as an indicator of MPA effectiveness for species recovery than the more commonly used indicators of species-specific total biomass, density, or mean size (Pelletier et al. 2005, White et al. 2021). This aligns with current understanding of the effects of human activities on the body size structure of fished marine species (Bosch et al. 2022) and the importance of recovering age structures for overall population recovery (e.g., mediated by increased fecundity of larger females; Hixon et al. 2014, Ohlberger et al. 2022). However, **mean body length** can also be indicative of MPA effectiveness for species strongly targeted by fishing prior to MPA establishment (Jaco and Steele 2020).

Depending on management objectives, indicators may also be related to **species behavior, phenology, or health** (i.e., disease or physical damage), but generally secondary to the essential indicators noted above. For example, where MPA management objectives are focused on reducing the impacts of vessel traffic on whales, changes in localized behaviour (Lusseau et al. 2009) may represent an indicator of localized benefits of MPAs, while other metrics such as the level of contaminants in tissue samples from individuals or the fraction of individuals showing fresh scars from contact with vessels or fishing gear may be useful indicators of broader, regional-scale changes in management regimes associated with the implementation of MPA networks that would be difficult to ascribe to a single MPA (DFO 2022).

Among species-level indicators, those that are more challenging or resource-intensive to measure, such as abundance and population structure, are typically constrained to a small subset of focal species (Meehan et al. 2020). Such focal species are typically chosen through a collaborative multi-stakeholder process based on their ecological, socio-cultural, or economic importance, whether positive (e.g., habitat forming, threatened, fishable) or negative (e.g., invasive species) (Burt et al. 2014, Pendred et al. 2016, Hummel et al. 2022, Cardoso-Andrade et al. 2022). Notably, focal species abundance and population structure are among the leading indicators used for assessing management effectiveness itself across MPANs (Meehan et al. 2020).

Importantly, species indicators also encompass **biogenic habitats** formed by foundation species–such as kelp, seagrasses, oyster and other bivalve reefs in shallower coastal waters, as well as cold-water coral, sea pens, and glass sponge reefs in deeper waters (Rubidge et al. 2016, 2020) - which support a wide range of ecological processes and relationships (Angelini et al 2011). Foundation species often are identified as focal species and conservation priorities warranting more intensive monitoring to understand changes in their status and distribution and the implications of these changes for other species (Carr et al. 2011). In this sense, biogenic habitats can also be considered predictors for understanding changes to other species. The status and distribution of biogenic features is expected to respond to environmental change, level of protection within MPAs, and also to direct habitat restoration efforts. Active restoration of biogenic habitats such as oysters, kelps, and marine plants has been shown to amplify the benefits of protection within MPAs both for habitat-forming species themselves and for other species that depend on them (Peters et al. 2017, Hopf et al. 2022b). **Non-biogenic habitats** such as rocky reef or soft sediments, on the other hand, are typically captured by environmental indicators (see previous section). In addition, there are synergies between these two types of habitats, where structural complexity tends to be highest when biogenic structures grow on more complex non-biogenic habitats, which can be associated with particularly high densities of some groundfishes (Stone et al. 2015, Rooper et al. 2019).

Habitat-forming or foundation species can pose a special challenge to monitoring because they are often widely distributed, which require tradeoffs between broad-scale for distribution (e.g., overall extent, fragmentation, patch shape and connectivity) and fine-scale monitoring for habitat characteristics and ecological function (e.g., seagrass stem or kelp stipe density, glass sponge reef filtration capacity) (Loh et al. 2019). However, recent technological developments in monitoring methods have made monitoring both habitat-forming species and marine species overall much more tractable than in the past.

Community-Scale Indicators

Communities are typically defined as groups of interacting species, though the nature and extent of these interactions may vary (Magurran et al. 2011). Species-level indicators are almost always paired with indicators of community characteristics, which typically include measures of **community-scale biomass or abundance, dominance, evenness, rarity, richness, and diversity** (Magurran et al. 2011, Soycan and Lewison 2015, O'Leary et al 2021). Among these, community-scale species richness and diversity are the leading indicators in use across MPANs and these are typically applied to assessing representation and replication of key areas of ecological importance rather than as measures of MPA effectiveness which tend to focus on species-scale indicators (Meehan et al. 2020).

However, comparative evaluations have shown that these indicators are not as well suited for detecting management effectiveness for community-level objectives and provide helpful insights into more informative indicators for MPA effectiveness (Pelletier et al. 2005, Soycan and Lewison 2015). For example, although species diversity and richness do tend to be higher inside than outside protected areas *on average* (Baskett and Barnett 2015, Hollitzer et al. 2023), species richness and diversity indices often did not differ *consistently* between MPAs and control sites, whereas **total biomass** and **total abundance** were consistently different between MPA and control sites and cited as more relevant to management. Of the two, responses derived from community-level biomass data were found to be the most reliable predictor of MPA effects (Pelletier et al. 2005, Soycan and Lewison 2015). The findings that species richness and diversity tend to not differ consistently different between MPAs and control sites while biomass and abundance do is often attributed to **context-specific trophic cascades** resulting from protection and modulated by prior fishing effects at the site being evaluated (Micheli et al. 2004, Baskett and Barnett 2015). For example, in some contexts, as the number and size of previously fished predatory species rebounds and their prey species decline (Soycan et al. 2015), there can sometimes be a net loss of species richness (Dalongeville et al. 2022). In other cases, where a rebound in predators leads to a decline of prey that negatively affects overall habitat complexity, there can be a net gain in diversity (e.g., as is the case for re-establishing sea otters reducing populations of sea urchins that eat kelp and result in the recovery of kelp forests benefiting many other species, Miller et al. 2018).

However, alternative metrics of diversity exist that have been found to be more reliable indicators of MPA effects on community diversity itself. These include: **evenness,** which describes the relative abundance of species and is sometimes defined for specific classes such as the ratio of pelagic to benthic species or predatory to herbivorous species (Blowes et al. 2019, Dalongeville et al. 2022); **functional diversity**, which captures the range of body size, habitat use, trophic level, foraging strategies and reproductive and behavioral strategies across the community; and **phylogenetic diversity**, which captures the diversity or breadth of evolutionary histories across the community and is sometimes used as a proxy for unmeasured functional diversity (Dalongeville et al. 2022). In some cases, community-level indicators may be developed for specific monitoring technologies. For example, **ecoacoustic indicators** (reviewed in Minello et al. 2021), including the Acoustic Complexity Index (ACI), have been used to compare benthic biodiversity inside and outside of MPAs (Davies et al. 2020).

Beyond changes in community structure, changes in community interactions following protection, which often unfold across food webs, can be logistically challenging to measure and are less frequently monitored (Cheng et al. 2019). Such changes can be measured indirectly by monitoring changes in the **relative abundance of predator to prey species** and changes in associated predation risk (Cheng et al. 2019). They may also be measured more directly using methods such as stable isotope analysis to monitor proposed indicators such as **changes in consumer niche widths** (Olson et al. 2019), **mean trophic level** (Blanco et al. 2021), or **food web length and stability** (Mack et al. 2020) as an early signal of broader prey availability and increasing food web complexity in MPAs.

Where resources are limited, preferred community-scale indicators may depend on the management objectives and projected outcomes of each MPA given the history of past pressures that would be addressed through protection. For example, at sites with a history of intensive past fishing pressure and depressed populations, total abundance and biomass may better assess performance against objectives of population recovery for previously targeted species. However, at less disturbed sites with little or no history of fishing, diversity and richness indicators may be more suited to assess performance against objectives of maintaining biodiversity of the local community at the site scale and representation and replication of community features at the network scale. 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 (Soycan and Lewison 2015, Blowes et al. 2019).

Box 2: Monitoring Spillover

A community-scale indicator that is also relevant to social indicators and benefits is the measurement of fish **spillover effects**, particularly at previously fished sites (Stamoulis and Friedlander 2013)**.** The concept of spillover encompasses both **(1) larval spillover**, which is monitored using methods for tracking ecological connectivity at broader seascape scales (1000s of kilometers, see section on Network-Scale Indicators) as well as **(2) adult spillover**, which is monitored using species and community-scale indicators at more local scales (500 m to 5 km) and is the focus of this box.

Adult spillover refers to an increase in the size, density, and/or abundance of adults outside MPA boundaries that usually lags behind the increase in these metrics measured within an MPA. Although this lag varies based on age-dependent patterns of growth, natural mortality, and level of fishing mortality inside and outside of MPAs. A recent study suggest that overall timelines for biomass recovery through a filling-in process following establishment of an MPA can range from ~15-20 years for lingcod up to 40-60 years for china rockfish. This study also showed that there is a lag between timelines of biomass increase inside and outside of MPAs, with the effects spillover manifesting as fishery yield increases outside of MPAs on average 7 to 18 years following biomass increases in MPAs for commonly fished groundfish species of the Northeast Pacific Coast (e.g., Barceló et al. 2021). This type of spillover is typically evaluated in the immediate area beyond MPA boundaries, typically observed within 1-5 km of the boundary reflecting the dispersal distances of individual organisms (Stamoulis and Friedlander 2013, Ahmadia et al. 2015).

Establishing an *ecological spillover* effect for adults requires more intensive sampling of both fish or invertebrates (typically biomass) and habitats using underwater visual surveys, or underwater video in deepwater MPAs, at multiple scales and varying distances across the MPA boundary to disentangle the effects of habitat from MPA effects (Di Lorenzo et al. 2016, Sackett et al. 2017). Understanding whether this translates into a *fishery spillover* effect requires coupling this indicator to monitoring social indicators of fishing effort or catch per unit effort (CPUE), which tends to match biomass gradients across protected area boundaries (Stamoulis and Friedlander 2013, Di Lorenzo et al. 2016, 2020). For example, studies of local catch, fishing effort, and CPUE in the California spiny lobster fishery showed that increasing density, size, and biomass within MPAs was associated with increased total catches outside MPAs 6 years following MPA establishment, indicating that the trade-off of fishing ground for no-fishing zones in MPAs benefitted the fishery at local scales (Lenihan et al. 2021).

Successfully demonstrating these effects requires careful monitoring design that accounts for local conditions, species, and expected spillover timelines. It can also require considerable effort for the intensive sampling required to show effects over distance from the MPA. As a result, monitoring spillover is typically reserved for selected key fisheries species that are important to local fishing communities, and may be one indicator by which benefits of MPAs to communities are measured.

Network-Scale Indicators

Given that one of the primary objectives of MPAs within a network is to operate synergistically to yield benefits 'greater than the sum of their parts', network-scale ecological indicators are one of the key elements differentiating monitoring of networks from monitoring of individual sites (Grorud-Colvert et al. 2014).

Fundamental network-scale ecological effectiveness indicators include **representation**, **replication, and connectivity**. All three are strongly linked to the size, spacing, arrangement, and protection levels of MPAs within the network, which are typically defined through theoretical studies during the planning and design stage using the best available ecological knowledge to optimize performance against these three network-scale ecological indicators alongside other social and/or economic indicators (Balbar et al. 2020). Although the MPAN design process typically sets the 'initial condition' for all three of these indicators, ongoing monitoring of these indicators is important to assess whether the theoretical synergistic benefits of the MPAN are occurring, maintained over time as environmental and management contexts change, and continuing to meet network objectives (Grorud-Colvert et al. 2014, Roberts et al. 2018). Representation and replication may represent a lower priority for monitoring programs given that these indicators are likely to change more gradually than other indicators and that a considerable level of effort may be needed to re-assess these indicators across a large number of sites. However, these indicators may be more suitable for monitoring over longer timeframes (e.g., revisited at the time of decadal network reviews), or when material changes to the network occur (e.g., adding or degazetting sites, as in Roberts et al. 2018). In addition, representation and replication alone are not sufficient measures of MPA performance and should always be paired with more quantitative indicators of threat reduction and realized ecological response (Cockerell et al. 2020).

Representation is a measure of how well the network includes the full range and diversity of priority species, habitats, or other natural features found within the network region and /or component bioregion, and often emphasizes representation of designated biodiversity hotspots, sometimes also known as ecologically and biologically significant areas (EBSAs) (Meehan et al. 2020, Balbar et al. 2020). Representation can be assessed over time by comparing species- and community-scale indicators inside MPAs to those of adjacent control areas or to the region as a whole to understand whether specific species, communities, or ecological features are gained or lost from individual sites or the network as a whole in response to ecosystem recovery, changes in the level of protection at existing MPAs, addition of new MPAs, or broader environmental change (Grorud-Colvert et al. 2014; Soykan and Lewison 2015). Species, habitat, and community data can be rolled up into representation metrics such fraction of each bioregion or habitat type protected at different levels or as '*mean protection gap*' and '*mean target achievement'* to frame representation data with respect to how well it is meeting MPA management targets across species or ecological features of interest (Roberts et al. 2018, Jantke et al. 2018).

Replication is a measure of how many distinct occurrences or sites of specific seabed features, habitat classes, or other areas of importance are included across the network as a way to increase redundancy and resilience to unpredictable environmental change (Balbar et al. 2020). Measuring replication hinges on the definition of a replicate, which is generally defined as a habitat area large enough to capture most of the species that use a given habitat, and may vary across habitats and scales. Ideally, the minimum area for replicate would be established using field studies to develop species-area curves to determine the minimum area needed to capture a majority (e.g., 90%) of species using a habitat (Saarman et al. 2013, Young and Carr 2015, Balbar et al. 2020). Where these data are unavailable, ecological knowledge on species ecology and behavior can be used to estimate an appropriate patch size (Balbar et al. 2020). Once a replicate is defined, replication can be determined using similar methods as for representation.

Connectivity is an emergent property of the configuration of MPANs that measures functional linkages between individual MPAs within the network mediated through the movement of organisms (gametes, juveniles, or adults), genes, energy, chemicals, or materials among habitats, populations, communities, or ecosystems (Carr et al. 2017, Balbar et al. 2020). Connectivity can be a key driver of MPAN design, but is more often a secondary consideration to other conservation and management objectives (Grorud-Colvert et al 2014, Balbar and Metaxas 2019, Balbar et al. 2020). Importantly, **connectivity is a key design attribute of MPA networks** and is the primary indicator of whether a collection of MPA sites is performing as a functional network to deliver benefits that are greater than the sum of its parts (Grorud-Colvert et al. 2014, CDFW 2022).

Connectivity can be defined through at least four different indicators, each of which are associated with specific types of information and monitoring methods that often draw on species- or community-scale indicators (summarized in greater detail in Balbar et al. 2022):

- **Landscape connectivity** describes the degree to which a landscape (or seascape) facilitates or impedes movement among habitats, populations, communities or ecosystems. This type of connectivity is typically assessed through the spatial configuration of MPAs within a network, often coupled with understanding of species dispersal phenotype (e..g, based on parameters such as pelagic larval duration (PLD), precompetency period of development prior to being able to settle, larval mortality, and spawning window) and connectivity modelling. For example, connectivity modelling can be used to demonstrate that many groups of MPAs currently referred to as networks may not be fully connected into a functional connectivity network, but are more accurately described as a collection of smaller functional networks (e.g., as is the case for the Australian national MPA network, per Roberts et al. 2021) which can influence decisions about current management and future MPA site designation. Landscape connectivity is often used as a proxy for functional connectivity captured in the other indicators below, which can be challenging and costly to measure directly, especially over large spatial scales (Balbar et al. 2020).

- **Population demographic connectivity** describes the movement of organisms among patchy sub-populations or habitats. It is generally assessed for (1) dispersal of planktonic larvae using models informed by larval behaviour, planktonic larval duration, and ocean circulation using particle tracking models for selected focal species, and (2) dispersal of adult individuals using models informed by field-based dispersal data collected through visual observation of 'natural marks' on individuals (e.g., fluke markings on whales), geochemical signatures in hard calcified structures such as shells or otoliths, or through diverse types of passive or active tagging and tracking studies (Balbar et al. 2020). Using methods such as geochemical signatures that capture movement information across the entire lifespan can be particularly useful for understanding movement between habitats and regions across the life cycle, which may take individuals and species beyond the boundaries of individual MPAs within the network.
- **Population genetic connectivity** describes the movement of genes among distinct populations of a species as mediated through the movement of individual organisms. It is generally assessed using direct (e.g., tissue samples) or indirect (e.g., eDNA) genetic sampling and provides information on dispersal distances as well as realized population-scale connectivity through gene flow. Genetic information obtained through discrete sampling of individuals can be used to calculate dispersal from metrics such as isolation-by-distance relationship (IBD) or fixation index (F_{ST}) among populations (less resource intensive but require more assumptions), or yield direct metrics such as parentage and sibling relationships and clustering which can also provide information on recruitment (more resource intensive and only possible at small spatial scales). In contrast, genetic information needed to estimate gene flow at population scales requires more continuous sampling of individuals across the entire geographic range of interest (Balbar et al. 2020). Genetic information can also be used with connectivity and population models to assess the potential contribution of MPAs to fished populations beyond their boundaries (e.g., LePort et al. 2017).
- **Ecosystem connectivity** describes the movement of energy, nutrients, chemicals, or materials among habitats or ecosystems as mediated through the movement of individual organisms. It can be measured through geochemical methods such as analysis of stable isotopes within organic material or tissues that match chemical signatures of specific habitats, depths, or regions. Although this type of connectivity is

logistically challenging to measure, it may be used in specific contexts such as monitoring the movement of detritus and nutrients between sites (Balbar et al. 2020).

Because monitoring for many forms of connectivity can be complex and require significant investments of time, effort, and resources, it is often carried out only for selected focal species or derived for more generalized functional groupings of species (e.g., coastal benthic versus offshore pelagic species or short- versus long-pelagic duration species) (Balbar et al. 2020). Under this approach, generalized connectivity benchmarks could be developed to evaluate network-scale connectivity over time. One such example is *ProtConn*, a metric that quantifies the percentage of selected habitats or entire planning regions covered by connected protected areas (Saura et al. 2017).

Measuring network connectivity is essential for assessing whether the theoretical synergistic benefits of the MPAN are being realized at a network scale. Monitoring connectivity at multiple time points can also help to inform the placement of future MPAs in the network to improve connectivity in response to changing seascape and environmental conditions (Balbar et al. 2020). Information on connectivity can also be an important input to landscape-scale population models to assess population viability and conservation planning for key species (Balbar et al. 2020). For example, California has invested in the development of the California Connectivity Model to help answer questions related to network-scale effectiveness, which have helped to confirm that confirm that (1) MPAs are more connected to one another and other parts of the coast than areas outside of MPAs, and (2) that the positive effect of MPAs on the size and abundance of species within their boundaries also enhances their contribution to larval connectivity outside their boundaries (CDFW 2022, Appendix B.8). However, it is also important to acknowledge that MPAs are typically not isolated patches of suitable habitat, as might be the case for some terrestrial protected area networks, but rather patches defined by artificial boundaries embedded within a broader continuous seascape that remains largely suitable for species survival and dispersal (Costello and Connor 2019). Thus, managers are advised to consider connectivity of the MPAN within the broader context of connectivity across the seascape in which it is embedded (e.g., Friesen et al. 2019).

Summary of Methods and Tools

A wide range of established and emerging tools and methods are now available to monitor the status and trends of species and community indicators. These methods range from visual observations by divers, in-situ video captured by fixed or mobile underwater cameras, or remotely sensed imagery captured by aerial or satellite systems; acoustic data captured by echosounders, hydrophones, and telemetry systems; and direct sampling via experimental fishing and collection of field samples for laboratory analysis (e.g., eDNA, stable isotopes) (Minello et al. 2021, Ehrman et al. 2022). Where species are rare, threatened, and/or particularly sensitive to physical disturbance, non-intrusive monitoring methods such as optical observation, acoustic methods, or environmental DNA (eDNA) are generally preferred (Loh et al. 2019, Gold et al. 2021).

In general, network-scale ecological indicators are measured through collective and comparative analysis of site-scale environmental, species, and community indicators to detect emergent trends across sites. The tools and methods used span a range of temporal and spatial scales. Monitoring of representation and replication is often focused on habitats and relies on acoustic or satellite remote sensing to detect and map habitats over large areas, which can then be overlaid with and compared to the footprints of MPAs within the network (Balbar et al. 2020). Monitoring of connectivity uses a broad suite of methods ranging from indirect estimation based on knowledge of species dispersal and biophysical modelling to more complex and resource-intensive methods of direct measurement using visual observation, telemetry tracking, genetics, or stable isotope and otolith chemistry to understand changes over one generation, while coarser tools such as population genetics and evolutionary phylogenetics can track changes over multiple generations (Balbar et al. 2020). Selection of the most appropriate tools from a management perspective will depend on the MPAN objectives of interest.

Table 29: Summary of key ecological indicators for MPAs and MPANs along with representative examples of associated parameters, which should not be considered comprehensive. Indicators or parameters that are bolded were identified in prior reviews as leading indicators currently in use in MPAs or MPANs, while those marked with an asterisk (*) have been shown to be the most reliable indicators of MPA effectiveness (sources below table).

Indicator Class	Representative Parameters	Value of Information	Key Methods and Considerations
Species	• **Distribution*** • **Abundance*** (by key species)* • **Population structure*** (size and age structure, by key species)* • **Dispersal** • Health (disease, damage) • Behaviour • Phenology (life cycle event timing)	Information on distribution and dispersal provide insights into changes in species occupancy and connectivity across the MPAN, while information on abundance is critical for tracking population trends in response to protection or other human or environmental drivers. Information on abundance and population structure can be used to understand the effects of MPAs on recruitment and survivorship of the different age classes, which can in turn provide insights into the expected future trajectory of population recovery.	Species characteristics should be monitored across a representative range of taxonomic groups and habitats and is ideally paired with data collection on core oceanographic variables. Distribution can be detected using a wide range of methods including visual, acoustic, and genetic sampling. Indicators that are more time and resource intensive to monitor, such as abundance and population structure, are typically monitored for a selected subset of focal species chosen for their ecological (e.g., keystone or habitat forming species), cultural (e.g., subsistence species), and/or economic (e.g., species supporting fisheries or recreation activities) importance.
Community	• Taxonomic composition • **Species Diversity and Richness** • **Evenness** / Dominance / Rarity • **Total biomass*** • **Total abundance*** • **Functional diversity*** • **Phylogenetic diversity***	Taxonomic composition can be used to calculate indices of community composition such as species richness, diversity, evenness, dominance and rarity, which can provide insights into overall system function. This information is also important to understand MPA effectiveness as well as ongoing coverage of important natural areas across the MPAN in terms of biodiversity and richness hotspots (see below). Species diversity and richness are the most commonly used leading metrics, but recent work has shown that total biomass, abundance, evenness, and functional	Taxonomic composition can be assessed through underwater visual surveys (by divers or remotely operated vehicles or ROVs),through underwater acoustic surveys (ship-based sonar, acoustic profilers or echosounders, and hydrophones) through physical surface sampling surveys (catch per unit effort in fisheries-independent and fisheries-dependent programs), or through collection of eDNA (through active or passive sampling protocols).

Indicator Class	Representative Parameters	Value of Information	Key Methods and Considerations
		and phylogenetic diversity are more reliable metrics of MPA effectiveness.	
Connectivity	● **Size & Arrangement of MPAs*** ● Population connectivity (physical movement, genetic, demographic) ● Ecological process connectivity (trophic linkages, nutrient flows, and energy transfer)	Connectivity measures functional linkages between individual MPAs within the network mediated through the movement of organisms, genes, energy, chemicals, or materials among habitats, populations, communities, or ecosystems. Monitoring connectivity helps to assess whether the theoretical synergistic benefits of the MPAN are occurring and effectively contributing to meeting network objectives. Monitoring connectivity at multiple time points can also help to inform configuration of future MPAs within the existing network to adapt to changing landscape and environmental conditions. In general, these indicators are measured through collective and comparative analysis of site-scale environmental, species, and community indicators to detect emergent trends across sites.	This class encompasses many types of connectivity, methods, and considerations. In the absence of empirical monitoring data, ecological connectivity can be estimated indirectly from the size and arrangement of MPAs, ecological knowledge of species dispersal and life history characteristics, and ocean circulation through network modelling. Population connectivity can be monitored directly through a variety of means ranging from simpler physical, geochemical, or acoustic tagging and tracking to more complex stable isotope analysis and to population genetics). Ecological process connectivity is more challenging to measure but can be monitored through different combinations of stable isotope analysis, stomach content analysis, and condition / caloric content of foundational prey species.
Representation and Replication	● **Key biodiversity areas*** ● **Key species richness hotspots*** ● **Proportion of species or ecoregions distributions covered by MPAs***	Coverage of important natural areas is often assessed as part of the MPAN planning process, but ongoing assessment of these indicators through species, habitat, and community-level monitoring is necessary to ensure that representativeness is maintained over time as human activities and environmental conditions may shift.	Because the Aichi Target 11 emphasizes areas of importance for biodiversity, conservation, and ecosystem services, there will be a strong linkage between ecological indicators contributing to ecosystem services and the social benefits and indicators they support.

Sources: Pelletier et al. 2005, Soykan and Lewison 2015, Meehan et al. 2020, Balbar et al. 2020, O'Leary et al. 2021, Ehrman et al. 2022, Dalongeville et al. 2022

2.4.3 Social

Progress identifying social indicators and associated methods for social dimensions of MPANs has been slower than environmental and ecological dimensions. The UK marine strategy, for instance, does not include any social indicators apart from monitoring pressures from human activities such as trawling, contaminants and anthropogenic noise that occur at the intersection between people and the environment. In contrast, California, Oregon, and to a lesser extent New Zealand have begun to make progress with respect to developing social indicators for their respective marine protected area networks. In general social indicators related to marine protected area networks distinguish between **four core categories of indicators: livelihoods, health and safety, culture and identity, and social relationships**. However, much like the environmental and ecological indicators, **the relevance of specific indicators are influenced by site and network contexts** such as the relative importance of different livelihoods, and the **interests, values and needs of adjacent communities** (Muhl et al. 2022). These contextual influencing factors should be carefully accounted for in monitoring and analytical frameworks.

First, the **focus on livelihoods, and in particular fishing livelihoods** is not surprising given the potential for adverse impacts on the livelihoods and well-being of individuals that depend upon harvesting marine resources. Although there is some evidence that well-managed and designed marine protected areas can improve yields with negligible impacts on costs (Kerwath et al. 2013, Qu et al. 2021), they can also contribute to the marginalization of fishers and the communities in which they live (Christie 2004; Schreiber et al. 2022) and add to the cumulative effects of threats such as climate change (Gill et al. 2022). Monitoring the impacts of MPANs on the livelihoods of commercial fishers thus provides opportunities for commercial fishers and managers to understand the impacts of MPANs and inform adaptive management (as is equally true for traditional Indigenous fisheries and recreational fisheries). In California, indicators related to commercial fisheries are derived primarily from geographically distributed online focus groups (due at least in part to COVID-19 best practices) that combined individual surveys with group discussions. This format allowed researchers to collect individualized perspectives on topics ranging from **perceptions of changes in access to harvestable resources and livelihood impacts of MPAs** and then dig deeper to place these results in context through focus group discussions. In Oregon, changes in fishing effort and impacts were primarily assessed through models, surveys, and individual interviews that permitted insights about certain types of impacts but may neglect other types of impacts or concerns. Many expert recommendations and MPA monitoring activities may also consider including indicators related to **tourism-based livelihoods** (Pham 2020; Picone et al. 2020; Rahman et al. 2022). In California, assessments included focus groups with commercial passenger fishing vessels. Oregon assessments combined business surveys and secondary datasets to develop a better understanding of the impacts of MPAs on indicators such as employment in tourism (Fox and Swearingen 2021) and perspectives of local businesses.

Second, many experts and monitoring programs recommended moving beyond just livelihoods to monitor the status and trends of other social indicators. MPAs can have a range of positive and negative effects on the health and safety of people. Protection of certain habitats, can for instance, serve to reduce the **vulnerability of coastal communities** to extreme events (Soanes et al. 2021), and combine with a range of other social, economic and governance factors to influence their overall **vulnerability and adaptive capacity of individuals, households, and communities** (Barnes et al. 2020). However, by restricting activities like fishing, MPAs and in particular MPANs that grow to encompass large geographic areas can have significant negative impacts on the abilities of nearby communities to have **access to nutritious and affordable food** and **maintain cultural practices and traditions** (Bennett et al. 2021; Gill et al. 2019). As a result it is important to monitor the status and trends of these indicators to inform adaptive management, which requires time and resources to work with partners to develop and organize surveys, interviews, and/or focus groups to collect these data.

MPANs can also generate or exacerbate **social conflicts among and between** different levels of government, government agencies, and different groups of stakeholders (Meehan et al. 2020). One of the main sources of conflict associated with MPAs is related to fishing. Fishers may see MPAs as a threat to livelihoods, as they restrict access to fishing grounds and can limit catches or increase costs. This can lead to tensions between fishers and government or management authorities, conservation organizations, and tourism operators perceived to benefit from restrictions (Lopes et al. 2017). Monitoring the status and trends of tensions are important as they can provide a leading indicator of potentially disruptive social conflicts to adaptively and proactively manage them and avoid broader impacts on the long-term governance of the MPA.

Third and finally, MPAN managers and stakeholders often benefit from including indicators of factors that do not directly measure impacts, but **indirect drivers** of impacts. These could include changes in fishing inputs costs, markets, and prices that may exacerbate economic impacts and tourism market information about environmental preferences and motivations that can inform development of initiatives, promotional materials, and educational activities.

Table 30: Summary of key social indicators for MPAs and MPANs along with examples of representative parameters.

Indicator class	Representative Parameters	Value of Information	Key Methods and Considerations
Livelihoods	• Employment • Income • Job satisfaction • Perceived impacts on livelihoods • Material style of life • Fishing patterns • Poverty • Impacts on business	Information about the status and trends of ocean-based livelihoods, especially fishing and tourism can provide valuable insights about the social and economic impacts on groups that may face the most significant costs and benefits from MPAs and enable adaptive management.	Data concerning the social and economic impacts of MPAs on livelihoods can be collected in a variety of different ways, including secondary data analysis of census or other similar types of datasets, spatially explicit models, surveys, interviews, and focus groups. A variety of methods can be used to analyze data, ranging from before-after-control-impact (BACI) and other quantitative methods to descriptive case studies. It is also important to consider that while secondary data and surveys generally facilitate analysis of certain impacts, they may also neglect other types of unanticipated impacts or perceptions that could help to improve management.
Health and Safety	• Access to food • Food security • Perceptions of health • Emotional and mental health • Disaster preparedness • Sensitivity and adaptive capacity	Information about health and safety can generate important insights about how MPAs affect the wellbeing of communities and other stakeholders in a variety of direct and indirect ways.	Data on health and safety can be gathered from a range of different data sources, including secondary datasets, surveys, interviews and focus groups. Notably MPAs may influence sensitivity to disturbances and adaptive capacity in a variety of different ways that overlap with other social and governance indicators.

Indicator class	Representative Parameters	Value of Information	Key Methods and Considerations
Culture and identity	● Environmental values ● Non-use values ● Cultural sites/areas ● Cultural practices	Information about the values groups hold with respect to marine environments provide important information to inform planning and track impacts on the abilities of groups to satisfy those values.	Data related to cultural aspects of MPAs can be collected through surveys, interviews, and focus groups. Participatory mapping methods appear to be particularly useful for eliciting values and identifying specific locations that stakeholders identify.
Social relationships	● Internal relationships ● External relationships ● Trust ● Levels of conflict	Information about social relationships within and across groups can generate valuable insights about how MPAs are influencing trust and social cohesion within communities.	Data about social relationships and conflicts are generally collected through interviews and surveys that measure trust, or strength of relationships with different groups. Activity-based data from conflict resolution bodies or records from public meetings or reports may also be used to develop measures of conflicts.

Sources: California Human Dimensions: Commercial & CPFV Fishing Monitoring;Oregon Marine Reserves Human Dimensions Research Meehan et al. 2020, Breslow et al. 2016

2.4.4 Governance

Governance indicators of marine protected area networks encompass **a wide range of dimensions,** including pressures on social-ecological systems, legal and administrative foundations, property rights, stakeholder participation, capacity, integration, enforcement, monitoring and evaluation, and education and awareness**,** most of which serve to enable effective and lasting conservation (Ostrom 1990; Gutierrez et la. 2013; Cinner et al. 2016; Edgar et al. 2016). It is important to note that although we have included pressures as a governance indicator, there are debates as to where it belongs. Nonetheless, as one of the primary goals of MPAs and MPANs is to deliver conservation and livelihood benefits by alleviating anthropogenic threats, **pressure monitoring provides an important leading indicator of potential benefits that can take years or decades to develop** (Edgar et al. 2015).

Pressure monitoring in MPANs requires different methods to assess whether management is inducing changes in human behaviour and influencing the overall magnitude of threats. Spatial distribution of human uses such as fishing, and changes resulting from the designation of MPAs and MPANs have been assessed through combinations of data from vessel monitoring systems and logbooks (Eigaard et al. 2017; Ziegler et al. 2022), participatory mapping (Noble et al. 2021), and spatially explicit models[5]. Logbooks are also used as direct measures of reported bycatch of certain species, or used as a model input to support estimation of total bycatch. Most other anthropogenic pressures, including litter, contaminants and underwater noise, are collected through in-situ monitoring or sampling of water, sediments, and biota to assess concentrations or levels relative to some benchmark.

Monitoring of governance indicators, including **legal and administrative frameworks, property rights, stakeholder participation, capacity, integration, enforcement, environmental monitoring, and education and knowledge** can be assessed in a variety of ways. These include **desk-based assessments** of legal documents, management plans, and budgets to assess the adequacy of legislation; assessments may also consider rules for empowering management authorities, establishing the property rights of stakeholders, and enabling core activities such as patrols, environmental monitoring and awareness raising. **Activity-based indicators**, meanwhile, can also be used to provide high level measures of governance

[5] Decisions need to be made about how and where to include human pressures monitoring. Human activities indicators relate to governance but are also social indicators that influence ecological effectiveness.

dimensions by, for instance, reporting the number of public meetings (stakeholder participation), training sessions (capacity), patrols (enforcement), surveys (environmental monitoring) and educational events (education and knowledge). However, wherever possible primary data collected through **stakeholder surveys, interviews, and/or focus groups are preferred** to desk-based assessments and activity-based indicators to ensure that activities are having their intended impacts. For example, although more public meetings is generally conducive to stakeholder participation, it does not necessarily ensure representation of the voices, interests and needs of all stakeholders. As a result 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 the experiences and perceptions of those participants.

Table 31: Summary of key governance indicators for MPAs and MPANs along with examples of representative parameters.

Indicator Class	Representative Parameters	Value of Information	Key Methods and Considerations
Human Activity Pressures	• Bycatch (for MPAs that allow some types of fishing) • Underwater noise • Litter • Contaminants • Spatial distribution of threats	Information about pressures provide leading indicators of the effectiveness of management measures that may take years to decades or more to translate into desired social and ecological outcomes. Some indicators, such as the spatial distribution of threats can also provide information about externalities of management actions	Data for pressure monitoring data can be collected in a variety of ways, including vessel monitoring and in-situ sampling of water, sediments and/or biota. Spatial models and other statistical techniques can be used to extrapolate estimates to larger areas.
Legal and administrative frameworks	• Adequacy of legislation • Existence of a management body • Existence of a management plan	Information about the legal and administrative foundations of clearly defined rules that establish management bodies, plan, and ensure awareness of rules and regulations help to provide a foundation for lasting and effective conservation by providing mechanisms for governing MPANs.	Indicators for legal and administrative frameworks can be assessed through desk-based assessments that measure the presence or absence of certain elements or multi-stakeholder focus groups and surveys that assess the adequacy of those elements.
Property rights	• Access rights • Use rights • Management rights • Exclusion rights	Information about stakeholder rights to access, use, and contribute to the management of natural resources provides insights about adherence to legal requirements (where applicable) and incentives, opportunities and constraints different stakeholders face as a result of the MPAN.	Indicators for property rights can be assessed through desk-based assessments that measure the presence or absence of legal rights for each group of stakeholders or stakeholder-specific focus groups and surveys that assess their perceptions of those rights.

Indicator Class	Representative Parameters	Value of Information	Key Methods and Considerations
Stakeholder participation	• Interaction with stakeholders • Level of stakeholder participation • Level of stakeholder support	Information about participation in conservation planning, management, and evaluation provides insights about levels of stakeholder interest and support for MPANs and the types of knowledge that are used to inform planning and adaptive management.	Participation can be assessed using a variety of different methods, including analysis of secondary data such as records of attendance at public meetings or surveys, interviews, and focus groups that assess both participation and perceptions of stakeholder influence.
Capacity	• Adequate human resources • Training • Reliable funding	Information about human resources and financial capacity provides insights into the adequacy of skills, knowledge, time, and resources that management possesses to undertake management functions.	Capacity can be assessed using a variety of methods, including desk-based assessments of features such as counts of human resources, budgets, training activities, or multi-stakeholder focus groups and surveys that assess the adequacy of human and financial resources.
Integration	• Level of regional cooperation • Integrated management measures • Governance networks	Information about integration provides insights about the extent to which policies and governance systems across different levels of government, agencies and management authorities are coordinated to achieve the objectives of a management plan. In general, effective management is enabled by coordinated policies and networks across relevant actors.	Integrated management can be assessed using a variety of methods, including desk-based assessments of governance networks and policies cooperation based on meeting records and policies, or surveys and interviews that collect details on perceived levels of integration and network ties.

Indicator Class	Representative Parameters	Value of Information	Key Methods and Considerations
Enforcement	● Compliance ● Number of offenses ● Number of patrols ● Enforcement budget	Information about compliance and enforcement provides important insights about the extent to which levels of protection outlined in management plans and rules are in place, levels of deterrence and stakeholder acceptance, and where detailed spatially explicit data are available can inform adaptive management by adapting rules or enforcement processes.	Enforcement is generally assessed on the basis of activity-based information and desk-based assessments. Detailed spatially-explicit data about rule violations can help to improve rules and/or improve patrols and enforcement activities.
Education and knowledge	● Educational events ● Awareness of rules and regulations ● Awareness of MPAN	Information about environmental monitoring provides insights about the extent to which stakeholders and other actors are aware of the MPAN, rules and regulations and can help to build support by sharing knowledge of potential benefits and mechanisms.	Education and knowledge is generally assessed on the basis of activity-based information and stakeholder surveys. Activity reporting typically focuses on the number of educational events or participants, while surveys focus on awareness.

Sources: New Zealand Monitoring Plan; California Human Dimensions: Commercial & CPFV Fishing Monitoring;Oregon Marine Reserves Human Dimensions Research Meehan et al. 2020, Breslow et al. 2016

2.5 Indicator Selection Process

2.5.1 Indicator Selection Frameworks and Criteria

Although a wide range of potential monitoring indicators exist that are relevant to MPAs, not all provide equal information for a specific management context. As a result, a smaller and more manageable subset of indicators are usually chosen through a collaborative participatory process that seeks to balance many considerations, including scientific and community knowledge and values, relevance for management needs, and feasibility given capacity and resource constraints using predefined indicator selection criteria (Hayes et al. 2015, Pendred et al. 2016, Ho et al. 2018, Hummel et al. 2022, Cardoso-Andrade et al. 2022). Following the establishment of clear MPAN goals and objectives in prior steps, a typical indicator selection process unfolds across a series of common steps summarized below and in Figure 17.

First, it is necessary to **(1) define baseline conditions** across the area of interest. This step might include identifying the valued components of interest through an inclusive participatory process; identifying the threats to these valued components and their anticipated responses through expert knowledge, literature review, and the creation of conceptual models linking activities to pressures to impacts; and developing MPA management goals and objectives. In the case of MPANs, these steps have usually already taken place as part of the MPAN design process prior to beginning work on a monitoring strategy. However, this cycle may be repeated to develop a monitoring framework and indicators that are tailored to the management objectives of individual sub-regions or MPA sites within the network (Hayes et al. 2015).

Next, a list of **(2) candidate indicators are compiled** that relate to goals and objectives. This step usually begins by documenting existing indicators that are already being monitored across the area of interest which can take advantage of existing capacity and protocols, promote standardization, and help to maintain time series where monitoring was already occurring at MPA sites prior to designation (Pelletier 2020). The initial list of candidate indicators can then be assessed against the new MPA management objectives to identify gaps and expanded as needed to include new indicators drawn from expert knowledge, case studies, or literature review documenting current best practice.

Candidate indicators are then screened through an **(3) indicator prioritization process** to establish their fit using predefined indicator selection criteria based on considerations such as as their relevance to management, conceptual validity, sensitivity to environmental change, measurability, understandability, and feasibility, among others (Rice and Rochet 2005, Smit et al. 2021). Numerous indicator selection criteria exist for selecting environmental and ecological indicators for marine and coastal settings (e.g., Rice and Rochet 2005; Kershner et al. 2011, Smit et al. 2021, Cardoso-Andrade et al. 2022) while a much smaller subset of frameworks offer guidance for the selection of social, biocultural, and well-being indicators (e.g., Breslow et al. 2018, DeRoy et al. 2019, Muhl et al. 2022), reflecting the broader historical bias towards biophysical indicators for MPA evaluation to date (Meehan et al. 2020, O'Leary et al. 2021). Importantly, ***relevance to one or more key management questions, objectives, and levers should be one of the most important selection criteria*** for indicators to ensure that monitoring data will be useful for decision-making. A representative list of common indicator selection criteria used for the prioritization of indicators of marine and MPA management effectiveness are summarized in Table 32. However, each MPA network typically chooses a subset of selection criteria from this broader 'menu' to suit its specific context and management needs.

Indicator selection is typically carried out through some combination of literature review, which can provide more rigorous scoring but may also be time and resource intensive, and expert-driven approaches, which are fast and efficient but may be subject to more bias and information gaps (Brown et al. 2019). In some cases, indicator selection may also be based on simulation modelling for 'performance-testing' of indicators under different management contexts to identify those indicators that yield the most consistent and directional signals of MPA effectiveness across different pressure scenarios despite environmental variability or uncertainty (Hayes et al. 2015, Brown et al. 2023). The approach that is ultimately selected will generally depend on staff, time, and financial constraints on the process.

For selected indicators, the next steps include **(4) implementation planning** though *indicator validation* of both existing indicators (e.g., to assess spatial gaps in coverage relation to MPA sites) and new indicators (e.g., to carry out pilot testing of methods and feasibility in field studies), identification of the *reference state*, and identification of *thresholds and targets* for the indicator in relation to management goals and objectives.

Much like MPA management itself, indicator selection should allow for adaptive management allowing for **(5) implementation, reporting, and refinement** over time, for example, by starting out with a broader subset of indicators and refining methods, consolidating and dropping indicators that are not providing sufficient value of information or proving impractical when applied in this new context, and potentially adding new indicators as novel techniques emerge that are better suited to monitoring needs (Loh et al. 2019).

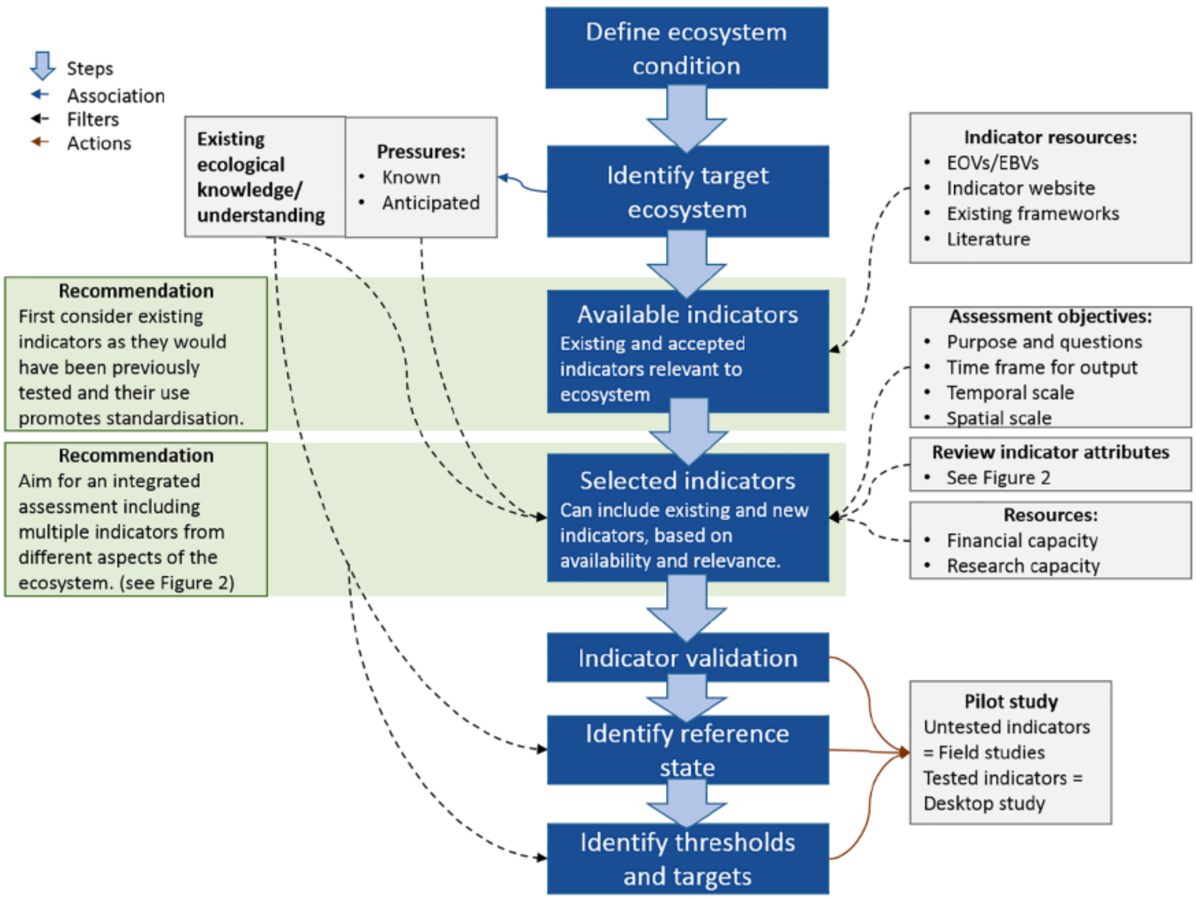


Figure 17: Conceptual framework for an indicator selection and prioritization process. Reproduced from Smit et al. (2021) and Ho et al. (2018).

Table 32: Representative indicator selection criteria used in prior marine and MPA monitoring frameworks, and a subset of criteria is chosen to suit the context and management needs of each MPAN.

Category	Criterion	Considerations
Management Criteria	***Relevant***	The indicator is socio-ecologically and geographically relevant and addresses at least one MPA Goals and Objectives, dimension (environmental, ecological, social, governance), or decision-making/management lever.
	Comprehensive	The indicator addresses more than one goal, objective, dimension (e.g., bio-cultural indicators), management lever, or MPA site.
	Understandable	The indicator is simple and intuitive to explain, has some level of public awareness or recognition through prior public outreach or reporting, and can be linked to community, cultural, and/or place-based values.
	Co-developed	The indicator has been developed in collaboration with communities it measures, and/or with collaborators who will be involved in measurement.
Technical Criteria	***Theoretically Sound***	A body of evidence exists to demonstrate a relationship between the indicator and key values, stressors, or management actions of interest, and ideally benchmarks or thresholds, such that the indicator acts as a reliable surrogate.
	Sensitive	The indicator predictably reflects the changing status of the value, pressure, and/or management action of interest.
	Scalable	The indicator is spatially relevant across the geographic area of interest, is of sufficient spatial and temporal resolution to inform management, and can be used at multiple scales of ecological or social organization. This criterion may also include considerations of compatibility with existing regional or national indicators to contextualize local changes in ecosystem status.
	Responsive	Considers the rate at which the indicator responds to changes in values of concern. 'Leading' indicators measure conditions that might foreshadow changes, whereas 'lagging' indicators measure whether the value itself is affected and by how much. In addition, indicators may also be classified as 'fast' or 'slow' in terms of how rapidly they respond to changes in the value of interest. Both types of variables are important. For example, MPA indicators directly tied to changes in important values of interest are often slow, lagging indicators (e.g., changes in biomass of slow-growing fish) and should be paired with fast or leading indicators (e.g., fishing effort, annual recruitment rates) to provide early indicators to inform a proactive management response (Walker et al. 2012, Kaur et al. 2020, Jaco and Steele 2020).
	Reliable	Accurate and robust, that is, measured with a low rate of error, not easily confounded by external sources of variability and uncertainty, and unambiguous in the interpretation of results.

Category	Criterion	Considerations
	Uniqueness, Complementary, and Connectedness	Considers the indicator in relation to others within a suite of indicators. For example, some values can be measured by only one or two unique indicators suited to this purpose that provide high value of information even if they do not score highly on other criteria (e.g., necessary for monitoring a specific habitat type or social dimension even if it is not scalable). Other values can be measured by a wide range of indicators, but only a small subset of these have the desirable property of varying independently from others in the suite (Longo et al. 2015). It is also important to consider how indicators in the suite are connected to other indicators and dimensions in ways that reflect the interconnectedness of coastal and marine socio-ecological systems (DeRoy et al. 2019).
	Prior Data Availability	The indicator is associated with historical and ideally continuous baseline data which document trends over time and space that can aid in the interpretation of future change.
Logistical Criteria	***Measurable***	Scientifically proven, accepted, and replicable protocols for direct measurement of the indicator exist.
	Feasible	Related to the complexity of the method(s) used for monitoring a given indicator and whether a monitoring program is already in place or, if not, whether implementation would require hiring specialized staff or delivering long-term specialized training. This is particularly relevant for indicators that are meant to be tracked through community-based monitoring programs and may potentially be given greater weight for those indicators.
	Timely	Planning, measurement, and data processing for this indicator can be accomplished quickly to deliver usable data in a timely manner. For example, real-time oceanographic sensors deliver data quickly with minimal handling and processing time, whereas tissue sampling followed by laboratory analysis for DNA or contaminants yields results more slowly.
	Low-Impact	Considers whether sampling of the indicator itself causes environmental impacts. For example, extractive ecological methods such as capture via experimental fishing or grab samples cause more impacts than non-extractive methods such as underwater video transects or eDNA sampling, and social science methods that aggregate data may have less impact on privacy concerns than those reporting disaggregated data.
	Cost-effective	Considers the monetary cost per sampling event including infrastructure, logistics, and human resources, relative to the value of information obtained.

Sources: Kershner et al. 2011, Werner et al. 2014, Longo et al. 2015, Breslow et al. 2018, DeRoy et al. 2019, Smit et al. 2021, Cardoso-Andrade et al. 2022. Sources for considerations relating to specific criteria are cited separately within the table.

2.5.2 Key Lessons Learned From Indicator Selection Efforts

Insights from prior indicator selection efforts for MPAs and other marine management context provide some key lessons to guide this process:

Indicator selection should occur through a collaborative process that captures the values of involved and affected communities

A collaborative indicator selection process ensures that the indicators selected capture the concerns, values, and voices of diverse communities of place or of interest such as First Nations, municipalities, boaters, fishers, non-profits, researchers, and others who may have been involved in or are affected by MPA establishment. Engagement should begin early and continue often over a series of meetings or workshops and helps to build mutual understanding and a sense of trust, ownership, and buy-in for monitoring activities and outcomes when these are framed in the context of indicators communities care about. It is also particularly important when effective monitoring will rely on partnerships with individuals or organizations representing these communities (Brown et al. 2019, Pelletier et al. 2020, Sullivan-Stack et al. 2022). Whenever possible, the collaboration strategy should be co-created with participants to ensure the process is tailored to the community and cultural context of participants to improve engagement, knowledge sharing, and outcomes (Yuen et al. 2017, DeRoy et al. 2019). In some cases, this may require non-standard approaches to engagement including storytelling, games, illustrated worksheets, and structured sorting exercises such as the Q-sort method for prioritization (Loring and Hinzman 2018, Zabala et al. 2018). 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 (Heck et al. 2011, Pendred et al. 2016, Mulh et al. 2022). An iterative participatory indicator selection process also offers an opportunity for building relationships and fostering communication and sharing of data and ideas that builds a foundation for ongoing collaboration for MPA monitoring, management, and reporting moving forward. The success of this participatory process hinges on the expertise of team members and leaders. Having a dedicated task leader with extensive knowledge of the regional context can help to accelerate identification of data considerations, recruitment of participants and reviewers, and facilitation of focused and productive collaboration throughout the process (Brown et al. 2019). Examples from British Columbia show some promising approaches to working on indicator selection across large and diverse participant groups (Gilani et al. 2018; Loring and Hinzman 2018).

Indicator selection should occur through a systematic, transparent, and repeatable process

Leveraging the many established indicator selection frameworks and criteria for marine and MPA management indicators as part of an inclusive and participatory process can help to reveal and mitigate personal or institutional bias of any single entity involved in the process, make it more likely to select indicators that will be effective for monitoring MPA outcomes rather than unrelated objectives. Such a process also provides more rigorous, defensible, and documented rationale for those not able to participate in the process and serves as a repository for institutional memory for those who become involved in MPAN evaluation later on, which is particularly valuable for participating organizations with high staff turnover. Finally, the use of a systematic and well-documented process enables a consistent and repeatable approach for re-evaluating existing indicators; for example, potentially replacing indicators that have not proven useful or considering the addition of new indicators (Samhouri et al. 2014, Brown et al. 2019).

Suites of indicators improve robustness of assessment and confidence in results

Indicators are often bundled into suites of complementary measures rather than used in isolation. Development of indicator suites can follow two main strategies. The first strategy is to use suites designed to measure *different aspects of the same attribute*, where the use of different indicators can help to create a 'portfolio effect' that mitigates bias or uncertainty in any one indicator and multiple indicators demonstrating similar patterns increases confidence in the results. However, this benefit is only realized when at least some indicators in the suite are 'orthogonal' or vary independently from each other in response to potential influencing factors, which also helps to reduce redundancy of indicators and increase overall efficiency of monitoring. Where this is not the case, all indicators may be subject to the same sources of bias and create false confidence in MPA effects that may actually be driven by external factors such as oceanographic conditions (Longo et al. 2015). The second strategy is to use suites designed to *measure multiple attributes of the same broader system*. This strategy often aims to include indicators from each of the different themes captured in this section (e.g., environmental, ecological, social, governance, and pressure indicators) to provide a more multidimensional and holistic picture of the effects of MPAs on the broader socio-ecological system (Longo et al. 2015, Meehan et al. 2020). The goal is to identify the smallest, well-rounded suite of indicators able to yield the desired information. To do so, additional 'suite-level' selection criteria can be used to assess complementarity and redundancy across suites of candidate indicators to ensure they include a balanced mix of indicators relevant to multiple dimension, scales of organization, and leading or lagging response times (Kershner et al. 2011, Breslow et al. 2018).

Suites of indicators should consider relationships and interdependencies between indicators and dimensions

Suites of indicators may reflect the status of individual components of a socio-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 and across dimensions of coastal and marine ecosystems. One approach to better representing this interconnectedness is to develop suites of **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. Indicators related to ecosystem services (Olander et al. 2018) (**Figure 18**). Indicators relevant to the ecosystem services along these causal chains are known as **benefit-relevant indicators (BRIs).** BRIs are useful because they integrate information on cascading responses to a management action, in this case MPAs, across multiple dimensions of the socio-ecological system and in so doing move beyond measurement of changes in state to provide insights into changes in processes as well (see also Appendix A discussion on this topic at an MPA experts workshop). In many cases, BRIs act as a necessary proxy indicator for changes in social value indicators themselves, which can be challenging to measure in practice (Olander et al. 2018). This concept can be expanded to encompass not only the many ecosystem services MPAs can provide to people (Marcos et al. 2021), but also the many '**services to ecosystems**' (S2E) that people can provide in return (Comberti et al. 2015). 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 (Bliege Bird and Nimmo 2018). 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 (DeRoy et al. 2019).

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.

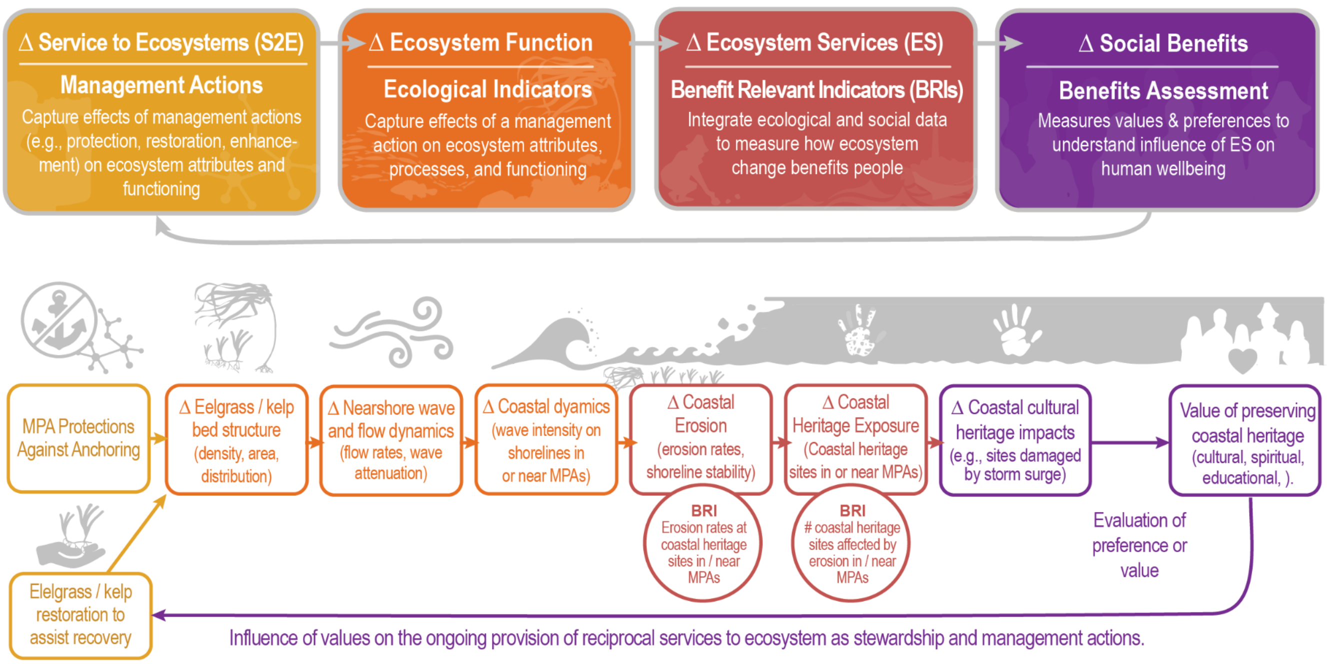


Figure 18: Example of a simple causal indicator chain for assessing the cascading effects of a management action, such as establishment of an MPA, on ecological indicators, the ecosystem services that depend on ecosystem function, and the social values that in turn depend on ecosystems services. Benefit 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 and Olander et al. 2018.

Practitioners must balance trade-offs regarding the number of indicators chosen

Resource and capacity constraints will always limit the number of indicators that can be monitored consistently and effectively. The indicator selection process must thus balance trade-offs between monitoring too few indicators, which may fail to adequately capture the state of the system, and too many indicators, which reflect inadequate prioritization of goals and objectives and are more likely to compromise data quality and continuity when resources are spread too thin, result in the need for aggregate indicators which can obscure interpretation of results, and create challenges in communicating outcomes to stakeholders and rights-holders (Samhouri et al. 2014, Hayes et al. 2015, Resource Legacy Fund 2020). Using a smaller set of more inclusive or interconnected indicators that capture multiple aspects of a socio-ecological system can be one way to help balance these trade-offs (DeRoy et al. 2019). The prioritization process typically reduces a list of several hundred candidate indicators to a more manageable number which may be further refined and reduced following pilot testing (e.g., reduced from over 350 to 120 indicators for the Monterey Bay National Marine Sanctuary MPAs (Brown et al. 2019), from 132 to 37 indicators for Portuguese MPAs (Cardoso-Andrade et al. 2022).

The indicator selection process reveals key data gaps and future research priorities

In light of practical constraints on new monitoring activities, the indicator selection process often emphasizes indicators with readily available data that align with high-priority management objectives and other screening criteria. However, this process also naturally reveals high-priority indicators with little or no data availability. These indicators should be carefully documented along the way to provide a starting point for determining which data-poor indicators might warrant the initiation of a new monitoring activity and which might be better addressed through more focused priority research projects (Brown et al. 2019). Because of this fine line between monitoring and research questions, MPA or ecosystem-based management strategies are sometimes framed as joint monitoring and research strategies that distinguish ongoing monitoring from research activities for each key management objective or theme (e.g., SGSSI 2021). Explicitly identifying these data gaps signals opportunities for developing joint proposals with First Nations, academic institutions, eNGOs, or other partners to fill data gaps for inclusion in future rounds of MPA monitoring and assessment (Brown et al. 2019).

2.5.3 Selecting Indicators to Capture Climate Change Effects

Climate change is anticipated to have significant impacts on key species and habitats of conservation concern on the Pacific Coast and is likely to represent a critical confounding factor that will need to be accounted for in analyses assessing the effectiveness of MPAs and MPANs. This is particularly true given that MPANs are not expected to offer significant protection against many aspects of climate change, such as marine heat waves (Smith et al. 2023). Many of the same indicators used for monitoring the general effectiveness of MPAs are also useful for understanding broader climate change effects with appropriate sampling and analytical approaches specific to this context (Wilson et al. 2020). These types of indicators can be bundled into a sub-suite of indicators for focused reporting on climate change concerns. When selecting among indicators, it is important to differentiate predictors of climate vulnerability or risk which often do not account for adaptive capacity and other relevant processes (e.g., species life history characteristics and predicted probability of occurrence from species distribution models, such as in Lewis et al. 2023) from empirical indicators based on measurable, realized effects (e.g., northernmost observation of a species). Predictive indicators should be viewed as informing hypotheses about the effects of climate change on values that can be tested through the collection of empirical data, which can then in turn be used to update vulnerability indices and models to improve their predictive power.

The immediate environmental effects of climate change include changes in **sea water temperature** both at the surface and at depth, in **ocean acidification** (typically as the partial pressure of CO_2, or pCO_2, and pH), in the direction and strength of **ocean currents**, and in **net primary productivity** (typically as chlorophyll a), among others (Blanchard et al. 2012, Bryndum-Buchholz et al. 2022). Notably, many of these indicators covary – for example, primary productivity is affected by climate both directly (e.g., sea surface temperature) and indirectly (e.g., currents, upwellings, nutrient or light availability), with ramifications for broader ocean food webs (Blanchard et al. 2012, Krumhardt et al. 2017). Importantly, the monitoring and analysis of environmental variables must account for short-term climate oscillations (e.g., El Nino) against the background of long-term climate change which may only be possible following the accumulation of extended time series (e.g., Halpern and Cottenie 2006).

The cascading ecological effects of environmental changes include **changes in habitat and species connectivity, suitability, and ultimately distributions** associated with localized extinction or colonization. Climate change related changes in habitat connectivity can be predicted through modelling of either larval dispersal via the effects of changing ocean temperatures on pelagic larval duration (PLD) and thus dispersal distances (O’Connor et al. 2007), or modelling of seascape resistance to adult movement using data on mean dispersal distance and habitat suitability between MPAs (Coleman et al. 2017, Friesen et al. 2019, 2021).

However, these predictions must be tested through monitoring by empirical measurement, which we focus on here.

Climate change is known to have significant impacts on important temperate habitat-forming species, particularly kelp (e.g., Smale et al. 2020, Hollarsmith et al. 2022, Tamburello et al. 2022) and eelgrasses (Murphy et al. 2021, Graham et al. 2022). Monitoring for climate change impacts on these habitats is generally carried out using the same methods used for monitoring **habitat extent and condition** but is paired with simultaneous monitoring of key climate-change associated environmental variables as well as community-scale indicators for the assemblages that depend on them. However, changes in community structure are likely to lag behind changes in habitat and be most apparent at the lagging and leading edges of habitat extent where these habitats are being respectively lost or gained (e.g., Robinson et al. 2022, Beas-Luna et al. 2020).

Changes in environmental and habitat suitability are in turn expected to drive changes in the distribution of fish and invertebrates. On the British Columbia coast, a wide range of commercially and culturally important fish and invertebrate species are expected to respond to climate change by moving into deeper waters and / or experiencing northward range shifts of 10 to 40 km per decade, resulting in considerable turnover in the composition of ecological communities (Weatherdon et al. 2016, Thompson et al. 2022a). Monitoring programs should thus plan sampling accordingly to detect potential changes in species composition along multiple directions of change including latitude, longitude, and depth (Taheri et al. 2021). Species range shifts occur in stages and may involve expansions at the leading edge of the range or contractions at the lagging edge of the latitudinal or depth range (Bates et al. 2013, Lloret et al. 2015). A particular challenge with assessing range shifts is that available data tend to be sparse at the range edge (Przeslawski et al. 2012), although there are a number of emerging monitoring and analytical methods to better detect changes in the leading and lagging edges of species ranges (Bates et al. 2013, Amorim et al. 2014, Fogarty et al. 2017; Karp et al. 2018). Studies have shown that **'first sightings'** can be reliable early warning signs of range shifts, as these sightings are likely related to long-term climate changes. Other potential indicators include **changes in relative abundance** of the community assemblage as well as the position of the **position of the leading edge, lagging edge, and mean position (centroid)** of species occurrence data points over time as assessed at both local and regional scales (Fogarty et al. 2017, Wilson et al. 2017). These can be documented through a wide range of multidisciplinary methods including local ecological knowledge and underwater surveys (Lloret et al. 2015), but eDNA monitoring may be particularly well-suited for its sensitivity in monitoring changes in the entire community assemblage and for detecting first occurrences of rare species as is the case in the use of eDNA for early detection of invasive species introductions (e.g., Gold et al. 2021, Bowers et al. 2021, He et al. 2022). To make robust inferences, the interpretation of data related to changing species distributions should consider range shifts in all directions, consider multiple possible drivers of shifts beyond climate change, and distinguish patterns from those expected by random chance (Taheri et al. 2021).

Monitoring of climate-related changes in the distribution of habitat, species, and human activities will help to understand whether climate modelling predictions for the region are being fulfilled, particularly in predicted climate change hotspots and refugia, and inform proactive planning and policy-making that anticipates future climate conditions (Fogarty et al. 2017). For example, monitoring changes in environmental conditions and essential fish and invertebrate habitats may provide an early warning of impending changes to species distributions, enabling implementation of proactive management strategies (Anderson et al. 2015, Karp et al. 2019). In addition, where range shifts do occur, they are likely to alter habitat and species composition and potentially change the degree of **connectivity** and **representation** across the MPAN in ways that constrain its ability to meet its management goals and objectives and may require alternative management strategies to maintain conservation benefits (Wilson et al. 2017).

2.6 Data Collection

2.6.1 Key Considerations for Data Collection Methods in MPANs

Deciding on the methods and tools that will be used to collect data on indicators and developing plans for how they are deployed are key elements of designing an MPA monitoring framework. This process is typically iterative and initiated alongside the selection of indicators themselves, as the technical complexity, feasibility, timeliness and cost of monitoring methods are included in most indicator selection criteria (**Table 3**), and the process is further refined as more detailed monitoring plans are developed.

This section provides an overview of key considerations for data collection within the design of a broader monitoring framework, beginning with an **overview of established and emerging monitoring methods and tools** for data collection that synthesizes the benefits, trade-offs, and considerations associated with each method, depending on the scientific questions and indicators of interest to inform the development of a broad MPAN monitoring strategy. This strategy must then be translated into a concrete monitoring plan based on robust **monitoring and sampling designs** to ensure that monitoring is occurring at the right places and times to answer key management questions. The development of both monitoring strategies and plans must consider **coordination** across entities that will be involved in data collection to reduce duplication of efforts and ensure wise use of limited resources across the MPAN. Successful coordination typically involves some **standardization of methods** to improve data interoperability and facilitate data aggregation across sites within the network, which will be needed to understand the effectiveness of the network as a whole (Buck et al. 2019).

Importantly, despite the growing toolbox of informative and increasingly complex methods and technologies applicable to short- and long-term monitoring of MPAs, decisions about which to adopt and how they are deployed through sampling designs are often ultimately constrained by logistical, financial, and human capacity (Milosavich et al. 2019, Benway et al. 2019).

2.6.2 Tools and Methods

The number and sophistication of methods and tools available for monitoring marine and coastal systems, including MPAs, has grown rapidly with recent technological advancements. Where marine monitoring once relied primarily on time- and labour-intensive field surveys, the advent of new electronic, remote sensing, and molecular biology methods are expanding our ability to monitor a wider range of indicators more efficiently (Maxwell et al. 2014, Mack et al. 2020, Danovaro et al. 2021). Each of these methods comes with its own trade-offs that can vary within specific monitoring contexts. For example, the feasibility of any given method will depend on factors such as the indicator of interest, spatial considerations (e.g., remoteness, number of sites, distance between sites, diversity of monitoring needs within and across sites), environmental conditions (e.g., water clarity, weather conditions), local geography (e.g., distance from coast, depth), and data processing and management needs. Moreover, because the length of a time series is one of the most critical determinants of statistical power to detect change, managers should be cautious about replacing traditional monitoring tools and methods with emerging methods until newer methods have been validated as providing nearly identical information. Instead, combining traditional and emerging tools and methods can provide complementary ways to collect a much broader range of data capable of answering both old and new management questions (Ratnarajah et al. 2023)

This section provides a high-level summary of key established and emerging monitoring tools and methods relevant to monitoring a wide range of indicators and metrics relevant to MPAs. Established tools include a wide range of conventional methods long in use for the monitoring of marine ecosystems and protected areas, including manual water and sediment sampling, surface or dive-based visual surveys, plankton tows, fishery-independent or fishery-dependent capture surveys. These methods have been comprehensively reviewed elsewhere (e.g., Murphy and Jenkins 2010, Bean et al. 2017), they are not revisited here in favor of covering emerging and innovative applications of existing tools or novel methods and tools relevant to MPAN monitoring contexts. Importantly, the emergent properties of data collected using these techniques, including status and effectiveness of individual MPAs and of the MPAN as a whole, are contingent on **robust sampling design** and **careful analysis** of monitoring data.

Artificial Substrates

<u>Key Dimensions and Indicators</u>: Ecological (species occurrence, spatial distribution, abundance, community composition, demographics, and connectivity)

Artificial substrates are sampling devices mimicking complex habitats that can be used to collect standardized information on specific biological communities and particularly juvenile **recruitment** over short or long timeframes (Mack et al. 2020). Different types of artificial substrate exist for targeting different parts of the ecological community answering different monitoring questions.

For example, **standard monitoring unit for the recruitment of reef fishes (SMURFs)** consist of a cylinder of plastic mesh containing coiled mesh or rope to mimic complex habitat desirable as a shelter for larval fish that can be deployed at different depths to collect samples of larval or post-larval fish ready to recruit to benthic habitat (Amman et al. 2004, Haggarty et al. 2017). This method has been widely used to monitor fish recruitment, including in relation to protected areas (e.g., for rockfish, Haggarty et al. 2017). Similarly, the **Autonomous Reef Monitoring Structure (ARMS),** mimics the complex structure of hard benthic habitats like rocks or reefs, while an **Artificial Substrate Unit (ASU)** mimics the structure of soft corals, sponges, or seagrass (Kenyon et al. 1999, DEVOTES 2013, Cahill et al. 2018, Adamczyk et al. 2022). Using more than one type of artificial substrate can help to obtain better estimates of recruitment across species targeting different habitat types within and across MPAs. Moreover, visual analysis of samples collected using these methods can now be paired with environmental DNA (eDNA) methods described later in this section for more comprehensive species identification (Cahill et al. 2018, Mack et al. 2020).

These devices can be valuable for facilitating monitoring of recruitment processes, which can be challenging to measure by other means, and for enabling standardized sampling of hard-bottom communities to produce comparable monitoring data across sites within an MPAN (Mack et al. 2020). Such monitoring can also provide crucial **baseline data** on variation in levels of recruitment across MPA sites within a network which, along with prior fishing pressure, exert a strong influence on the **trajectory and detectability of recovery** following protection and aid in the interpretation of subsequent monitoring data (Nickols et al. 2019, Hopf et al. 2022c).

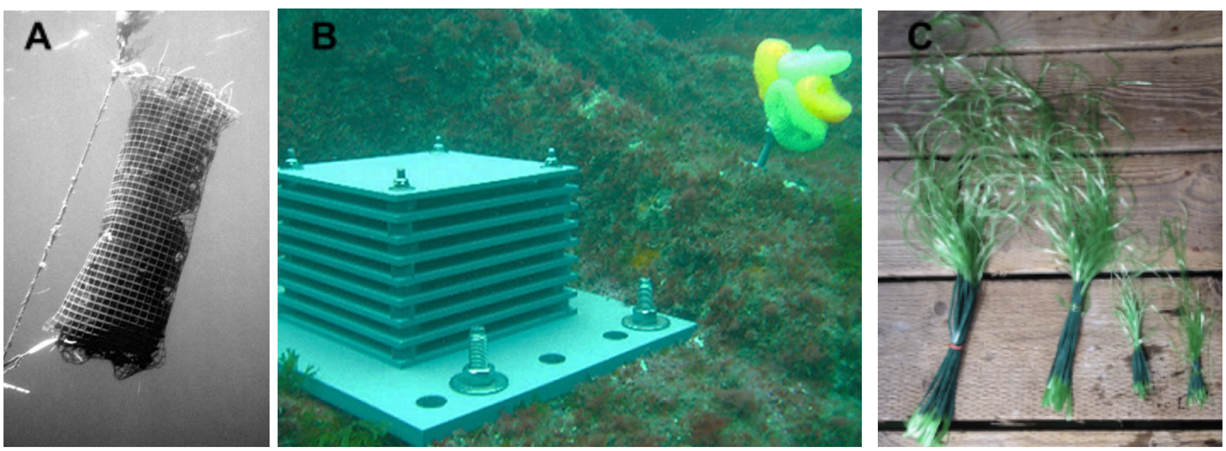


Figure 19: Examples of artificial substrates including (A) a SMURF (Amman 2004), (B) ARMS (left) and ASU mimicking sponges (right)(Credit: AZTI Tecnalia in Mack et al. 2020), as well as (C) an ASU mimicking seagrass for deployment on a flat grid on the seafloor (Credit: Adamczyk et al. 2022).

Electronic Instrumentation Methods

Electronic instruments can extend the temporal and spatial frames of data collection in marine systems by supporting continuous data collection at depths and in areas that are not typically accessible for direct human observation. Some are deployed at fixed locations that are regularly staffed or checked (e.g., coastal light stations, moored buoys), while others are mobile and deployed as and when needed. These instruments can provide information on a wide range of dimensions and indicators relevant to MPA and MPAN management, particularly across pelagic and deep ocean habitats far from shore (Danovaro et al. 2017, 2020).

In-Situ Chemical and Optical Sensors

Key Dimensions and Indicators: Environmental (water quality, primary productivity, bathymetry, coastal features), Ecological (planktonic species occurrence, spatial distribution, abundance, community composition)

Physical and chemical sensors housed within free-falling, free-floating, moored, or bottom-mounted **buoys, platforms, or profilers** enable automated continuous measurement of **physical and hydrographic conditions** that can help to provide important information on localized and regional changes in environmental conditions which can be helpful for interpreting studies of MPA effectiveness (Danovaro et al. 2017, Mack et al. 2020). Flow-through sensor systems such as the FerryBox may also be permanently mounted on vessels for long-term continuous monitoring of environmental parameters over a set route of travel, such as a ferry or shipping route, enabling broader spatial and temporal coverage than might otherwise be possible with time-limited research cruises (Mack et al. 2020). For example, Ocean Networks Canada operates mobile sensor networks deployed in the hulls of BC Ferries to enable monitoring of oceanographic conditions during daily sailings (Moran et al. 2022), and such systems could be expanded to include routes that transit through MPANs for more extensive coverage of monitoring across multiple sites. New sensors can continuously be added to these platforms to monitor new parameters as technology improves. For example, a fluorometric sensor was recently developed for the **real-time detection of oil pollution** as part of flow-through sensor systems in SmartBuoys or FerryBoxes (Part et al. 2021), which could significantly increase the sensitivity of oil pollution monitoring compared to what is currently possible through aerial overflights and act as an early warning system to prompt management intervention, particularly along busy vessel traffic routes passing through MPANs. Such sensors are becoming increasingly automated and connected through a networked marine ‘Internet of Things (IoT)’, opening up new possibilities for synchronized and event-based monitoring across large areas (Glaviano et al. 2022).

Long-term monitoring of plankton communities using **optical sensors** exists across many regions with MPANs (Eriksen et al. 2015), and is considered an integral part of the evaluation of ocean health for assessing ecosystem responses of primary producers and lower trophic levels to environmental change. In an MPA context, heterogeneity in plankton distributions can inform site selection to protect areas of naturally high productivity (Tweddle et al. 2018), while deviations from typical long-term trends in of plankton species composition, abundance, or biomass over space and time can also inform adaptive management by providing early signals of anomalous conditions, changes in recruitment, range expansions, the arrival of marine invasive species, the early stages of harmful algal blooms, and long-term climate change (Eriksen et al. 2019, Mack et al. 2020, Ratnarajah et al. 2023).

Whereas plankton species composition and relative abundance has been traditionally measured through time-intensive visual inspection by trained taxonomists in a lab, technological advancements in automated optical methods such as **optical imaging identification, fluorometry**, and **imaging flow cytometry** coupled with **automated optical imaging identification** algorithms using emerging technology such as machine learning offer fast and efficient high-throughput analysis of large samples of both phytoplankton and zooplankton, including ichthyoplankton or fish larvae (Spanbauer et al. 2020). These instruments are typically deployed from an oceanographic vessel or installed at fixed locations for long-term sampling and are capable of classifying and enumerating plankton through differences in optical properties such as size, shape, light absorption, pigmentation, and fluorescence under UV light (Danovaro et al. 2017, Spanbauer et al. 2020).

Many specific instruments within this class exist, each of which has been designed to answer specific research questions and comes with its own trade-offs (reviewed in Spanbauer et al. 2020). For example, some can provide coarser-level taxonomic information but cannot match the level of taxonomic detail possible through visual identification by trained taxonomists. To help overcome these limitations, some optical methods are being paired with eDNA molecular sensors or sampling that is capable of providing more detailed information on the species composition and relative abundance of organisms within plankton communities that is similar in its resolution but more efficient than visual identification by trained taxonomists (Ershova et al. 2021). Although the lack of reference samples for planktonic communities is an issue, their availability is steadily improving (Ratnarajah et al. 2023).

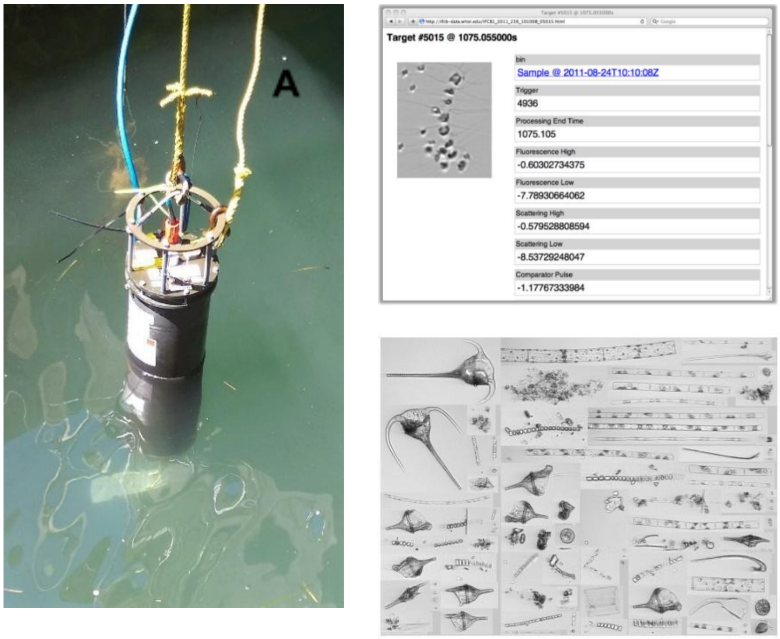


Figure 20: An example of an in-situ optical sensor used for characterizing plankton assemblages, the Imaging Flow CytoBot (IFCB), and its quantitative and visual outputs. Image credits T Crawford and Heidi Sosik for Woods Hole Oceanographic Institute (WHOI).

Remote Underwater Video Stations

Key Dimensions and Indicators: Ecological (species occurrence, size, abundance, community composition, behaviour, habitat status)

Remote underwater video stations are increasingly being used for standardized, cost-efficient, and non-destructive surveys of marine fish and invertebrate communities to overcome time, depth, and personnel limitations associated with more traditional survey methods such as dive-based surveys or the cost of more advanced survey methods such as underwater vehicles. This technique lends itself particularly well to standardized ecological monitoring through deployment of units across multiple sites within MPANs, which can facilitate data aggregation for whole network assessments of effectiveness while controlling for confounding factors that may be introduced when combining data from multiple monitoring methods (Knott et al. 2021). These units consist of one or two underwater video cameras and battery system in a housing mounted on a frame to raise it above the seabed over a standard soak time, after which the unit is retrieved for data download. The camera unit may be fixed for a constant field of view or may be paired with a motor to rotate at set intervals to capture a panoramic view of both organisms and surrounding habitats, and the use of two cameras allows for stereoscopic vision that improves the ability to measure the size and distance of objects in the frame (Langlois et al. 2020, Pelletier et al. 2021). Efforts to reduce the cost of such systems are ongoing and similar open-source designs such as the FishCam which is easily reproduced for less than $500 USD promise to make these methods more accessible to a wide range of organizations, potentially including community partners in MPAN monitoring (Mouy et al. 2020).

This method most often takes the form of **baited remote underwater video (BRUV)** (Figure 5 A) where bait, such as locally sourced oily fish in a mesh bag, is mounted on an arm in front of the camera to attract fish from the surrounding area to increase the likelihood of short-range observations for improved species identification and size measurement (Lanlois et al. 2020). However, this method is subject to **biases** related to bait attraction, trophic groups sampled, and behavioural conditions that can vary across spatial and temporal scales and oceanographic conditions (Wines et al. 2020). These biases can be mitigated through careful study design such as spatially balanced sampling, observations from both MPAs and reference sites, and accounting for confounding environmental variables in species distribution or other models based on BRUV data (Wines et al. 2020, Langlois et al. 2020). An alternative approach has been the development of **unbaited remote underwater video (URUV)** (Figure 5 B) protocols, which circumvent biases related to bait attraction and preclude the need for short soak times of 30 to 60 minutes to account for bait depletion, allowing for longer observation periods of 15 hours or more limited primarily by battery capacity (Pelletier et al. 2021).

Despite their acknowledged biases, and with careful attention to mitigating them, BRUVs have been widely used for MPA monitoring, including in **MPAN-scale assessments** of changes in the relative abundance and diversity of target and non-target fish species to demonstrate consistent benefits of protection despite subregional differences in fish assemblages measured (Knott et al. 2021, Bosch et al. 2022). Video monitoring is also particularly well-suited to monitoring rhythmic shifts in the presence and behaviour of different species and community assemblages that emerge across **day-night transitions** within MPAs, which can be logistically challenging to monitor using more instantaneous types of surveys (Hunojosa et al. 2020). Data from many BRUV monitoring sites can also be used as inputs to regional-scale predictive species distribution models of key ecological indicators such as abundance, richness, and biomass (**Figure 21 D**, Whitmarsh et al. 2023).

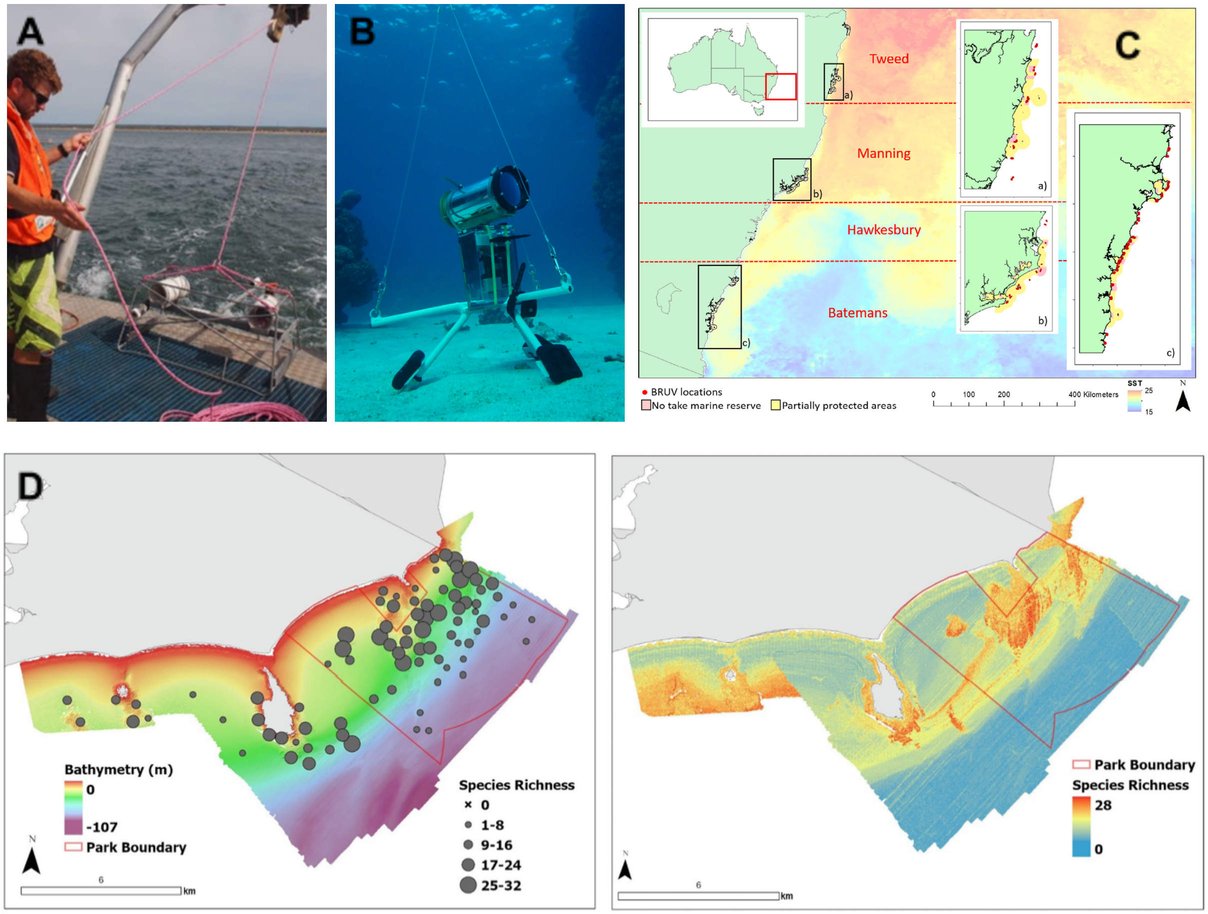


Figure 21: Deployment of (A) a stereoscopic baited remote underwater video (BRUV) unit (Credit: Langlois et al. 2020), a (B) panoramic unbaited remote underwater video (BRUV) unit (Credit: Pelletier et al. 2021), (C) an example of BRUV deployment (red dots) across multiple MPAs for assessment of the effects of protection on fish community recovery (Credit: Knott et al. 2021), and (D), an example of BRUV station data (left) used as an input to regional species distribution modelling of species richness (right) in the Cape Howe Marine National Park in the Victoria (Australia) MPAN (Credit: Whitmarsh et al. 2023).

Underwater Vehicles

<u>Key Dimensions and Indicators</u>: Environmental (water quality, primary productivity, acoustic environment), Ecological (species occurrence, abundance, community composition, behaviour)

Remotely operated vehicles (ROVs) are maneuverable or towed profilers connected to a vessel by cabling that can operate in three dimensions to collect data using a range of instruments including video cameras, sonar systems, and articulated arms used to collect samples or manipulate objects (Rosen and Lauerman 2016). These systems are often used as part of standardized survey methods for long-term monitoring, such as repeated measurements using photo quadrats or video transects for assessment of ecological communities. Because of their operational range, ROVs help to enhance spatial and temporal coverage of monitoring data across wider areas or collect high-resolution data in specific areas of interest, including to collect baseline data prior to MPA implementation and to assess the effectiveness of protection for sensitive deep-water habitats within MPAs, such as cold-water corals and sponge reefs (Rosen and Lauerman 2016, Vad et al. 2017, Mack et al. 2020). **Autonomous underwater vehicles (AUVs),** or their smaller and less costly counterparts **gliders**, can navigate along a preprogrammed route up to 1,500 m to generate horizontal profiles pf physical, chemical and biological parameters and are particularly useful for monitoring in deeper waters, inhospitable conditions, or in overhead environments such as under sea ice (Mack et al. 2020). Emerging technologies are also leading to the development of AUVs with novel sensors for detecting and analyzing trace pollutants such as hydrocarbons in situ (Danovaro et al. 2017) as well as growing potential for the use of machine learning algorithms for automated image processing and detection of underwater habitats and species (e.g., invasive species, Carvalho et al. 2023). Although the cost of these technologies still prohibits widespread use, it may one day be possible to program autonomous vehicles to follow set routes across all MPAs within a network for more complete monitoring than is currently possible.

Figure 22: Images of underwater vehicles including (A) remotely operated towed vehicle (Credit: Mark Artney in Mack et al. 2020), (B) an autonomous glider (Credit: Kimmo Tikka in Mack et al. 2020), and (C) a remotely operated vehicle (Credit: Ocean Networks Canada).

Cabled Marine Observatories

Key Dimensions and Indicators: Environmental (water quality, primary productivity, bathymetry, coastal features), Ecological (species occurrence, community composition)

Cabled seafloor marine observatories are capable of collecting continuous data on numerous parameters of interest for marine management. These platforms are capable of housing multiple instruments, including chemical, physical, acoustic, and optical sensors, that are connected to underwater cables for real-time data transmission to the surface and often allow its instruments to be powered from shore (Flagg et al. 2020). This configuration allows observatories to collect synchronized data on multiple parameters year-round and at high temporal resolution, particularly in the deep sea, facilitating contextual analysis of relationships between physical and ecological observations and overcoming limitations of many other methods limited by battery power or human time constraints (Danovaro et al. 2017, Flagg et al. 2020, Danovaro et al. 2020). Locations are strategically chosen with managers or partner communities to support local environmental monitoring programs and inform decision-making (Flagg et al. 2020).

For example, Ocean Networks Canada operates an extensive node-based network of large telecommunication cabled observatories through its NEPTUNE and VENUS networks (Figure 23) as well as smaller community-based cabled observatories and uncabled sensors collectively housing over 9,000 sensors across all three of Canada's coasts. This network has been used to help answer a wide range of ecological research questions on biogeochemical processes, biodiversity, behaviour, underwater noise, seismic activity, weather, and climate change. The network is supported by an extensive data management and archive system and associated open data portal intended to make over 10 years of data observations to date openly available to users around the world (Moran et al. 2022). Although it is not feasible to deploy such platforms at every site within a MPAN, existing networks can provide critical information about short- and long-term environmental change that is necessary for interpreting monitoring of other parameters of interest, while strategic deployment of additional community observatories can help provide more insights on performance of select MPA sites of particular importance.

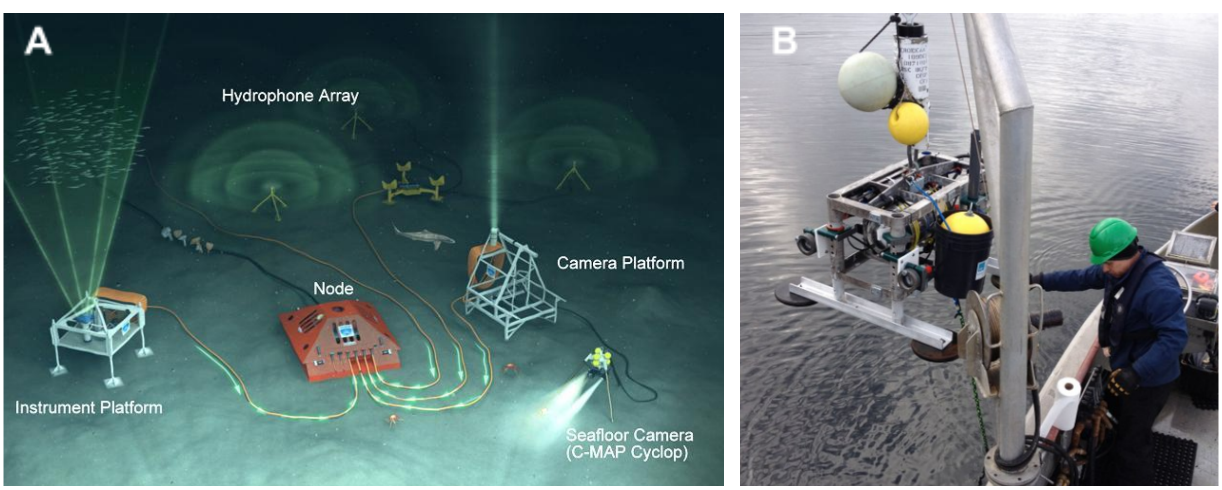


Figure 23: (A) Diagram of the components of a cabled ocean observatory node within the VENUS network and (B) deployment of a compact community observatory. Credits: Ocean Networks Canada.

Remote Sensing Methods

Remote sensing using optical, acoustic, satellite, and other electronic technologies has significantly advanced the potential for monitoring multiple dimensions and indicators of interest for assessment and management of MPAs, particularly MPANs extending over remote regions and large geographic scales, to provide a more comprehensive picture of marine ecosystems (Kachelriess et al. 2014, Maxwell et al. 2014, Danovaro et al. 2017, Mack et al. 2020).

Optical

Key Dimensions and Indicators: Environmental (water quality, primary productivity, bathymetry, coastal features), Ecological (species occurrence, spatial distribution, abundance, community composition), Governance (compliance, management effectiveness)

Optical remote sensing methods using a wide range of airborne and satellite sensors can support direct monitoring of **environmental conditions** such as sea surface temperature, salinity, and primary productivity (Merkohasanaj et al. 2019, Sagar et al. 2020) as well as the **distributions and characteristics of species** such as whales (Guirado et al. 2019) **and habitats** such as kelp (Nijland et al. 2019, Cavanaugh et al. 2021, Gendall et al. 2023) or seagrass beds (O'Neill et al. 2013, Merkohasanaj et al. 2019, Murphy et al. 2021). Careful study design and sequential image acquisition at multiple sites over multiple timepoints can be used to measure indicators such as the extent or density of seagrass and kelp habitats inside and outside MPAs over time (Merkohasanaj et al. 2019, Sagar et al. 2020).

There is also growing interest in the use of emerging **very high resolution (VHR) satellite imagery** for monitoring large-bodied **marine megafauna**, including sharks, pinnipeds, dolphins, and whales, to assess presence, abundance, density, distribution, and even health status by species for informing management decisions. Using VHR satellite imagery for monitoring marine megafauna would help to reduce barriers to monitoring in remote or inaccessible areas and over larger scales, including across MPAs, that would be challenging using more conventional monitoring methods using boat, land, or aerial platforms (Gendall et al. 2022, Tulloch et al. 2022). However, some limitations still present barriers to broader implementation of satellite monitoring of marine megafauna. These include *animal behaviour*, where animals can be difficult to detect when submerged, vertical, or more sparsely distributed; *weather conditions*, including cloudy days that tend to increase with latitude and rough seas open water which can make it challenging to detect animals amid large waves; *and cost*, which remains prohibitive at large regional scales (Guirado et al. 2019, Cavanaugh et al. 2021, Gendall et al. 2022). However, complementary monitoring methods such as visual observation, hydrophone recordings, or predictive forecasting of animal movements can be used in a ‘tip and cue’ workflow to trigger more focused acquisition of satellite imagery in areas with recent evidence of whale activity as well as issue alerts for marine management measures (Gendall et al. 2022).

Remote sensing technology is also increasingly being used to monitor **human pressures** on marine systems such as **pollution** from nutrient inputs (O’Neill et al. 2013), sediment inputs (Kostianoy et al. 2022a), or oil spills (Bertazzon et al. 2014, Kostianoy et al. 2022b), **fishing activity** (Rowlands et al. 2019), **vessel traffic** (Liu et al. 2017, Serra-Sogas et al. 2021), and **anchoring impacts** on marine ecosystems (Unsworth et al. 2017). This type of information can be used to assess management effectiveness for prohibited activities across MPANs and inform management action (e.g., Merkohasanaj et al. 2019).

In addition, both ecological and anthropogenic remote sensing data are often used to generate data layers that are necessary for **predictive modelling** of species, habitat, and human activity distributions (Danovaro et al. 2017).

Notably, **different remote sensing platforms** are associated with different capabilities and platform selection depends on the research question and desired spatial resolution of interest. For example, different earth observation satellites are associated with different resolutions, spectral bands, and imaging frequencies that influence their performance for different coastal and shallow-water monitoring applications such as measuring water quality, marine aquatic vegetation, or bathymetry (reviewed in Sagar et al. 2020, Cavanaugh et al. 2021). However, their use may be limited by poor weather conditions (e.g., cloud cover) or the costs of acquiring very high resolution imagery needed for specific applications such as object identification (Gendall et al. 2022). Aerial survey platforms such as piloted or unmanned aerial vehicles (AUVs) or drones and aerial coastal observatories (ACOs) that are flown at lower altitudes can overcome some of these challenges through the ability to fly below cloud cover and capture very high resolution imagery that can be used for finer-scale identification of marine species or their behaviours (Johnston et al. 2019, Mack et al. 2020). However, these low-altitude methods come with trade-offs including challenges surveying larger areas and the potential for behavioural responses of animals like marine mammals, reptiles, and birds to disturbance unless distance or elevation setbacks are applied (Bevan et al. 2018, Aubin et al. 2023).

Once acquired, the **analysis of raw satellite imagery** has historically been time- and labour-intensive, improvements in technology are now opening up possibilities for crowdsourcing or automated identification and classification of objects and areas in satellite imagery using machine and deep learning or neural networks based on known spectral properties (Cavanaugh et al. 2021) comparison to existing **reference image libraries** of both marine vessels (e.g., Liu et a. 2017, Bo et al. 2021, Kızılkaya et al. 2022) and fauna (e.g., Guirado et a. 2019, Cubaynes and Fretwell 2022). Moreover, all types of remote sensing benefit from **ground-truthing** with field observations to validate and improve the quality of remote sensing data, particularly in coastal and estuarine systems with high optical complexity (Danovaro et al. 2017).

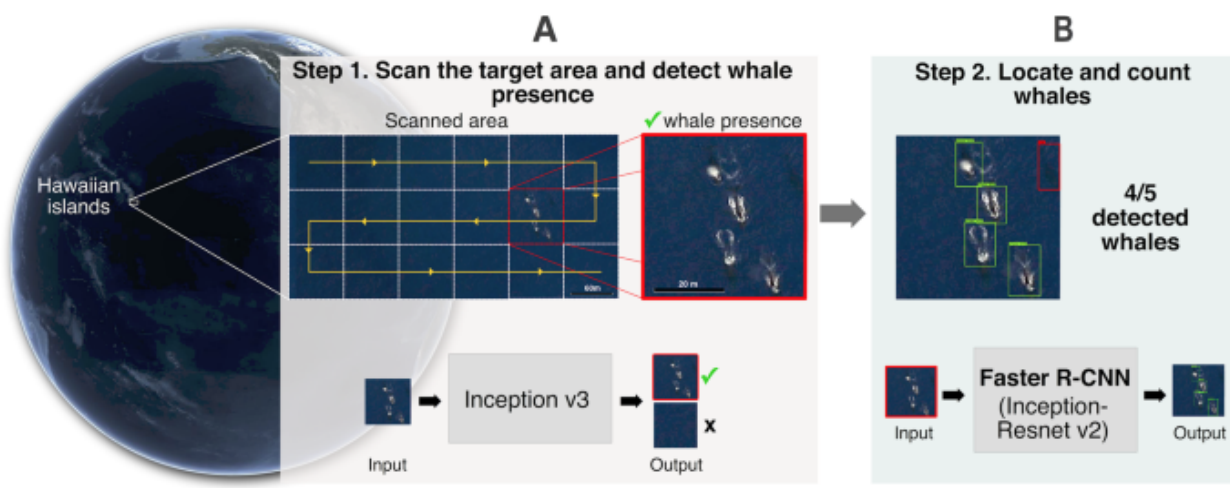


Figure 24: A visual representation of the protocol for identifying and counting whales in very high resolution (VRH) satellite imagery using machine learning, from a pilot application in the Hawaiian Islands. Credit: Guidaro et al. 2019.

Acoustic

<u>Key Dimensions and Indicators</u>: Environmental (bathymetry, coastal features), Ecological (distribution, body size, biomass), Governance (compliance, management effectiveness, pressures)

A wide range of established and emerging acoustic monitoring methods offer another non-invasive approach for monitoring marine organisms, ecosystems, and human pressures across MPANs that can overcome the visibility and depth limitations of optical remote sensing (Danovaro et a. 2017).

Active acoustic monitoring methods include technologies like radar and sonar that actively emit an acoustic signal and listen for reflections or 'echoes' to assess the distance, shape, size, composition, or other characteristics of the features of interest. For example, autonomous **coastal radar** stations can be used for continuous, fine-scale monitoring of **vessel traffic** tracks, volumes, and patterns within and around MPAs from a fixed location over time (Maxwell et al. 2014, Cope et al. 2022). Although they cannot identify individual vessels for enforcement action, they can be paired with timelapse or motion-activated cameras, also known as Self-Activated Photographic Device (SAPDs), to provide complementary information (Wilson et al. 2022). This method can also provide evidence of different **fishing behaviours** associated with targeting different focal species (e.g., meandering movements associated with line fishing, trapping or hauling nets, slow linear movements associated with trawling or trolling, and fast linear movements associated with transit) and document the **distribution of fishing** effort in relation to MPA boundaries to assess **compliance** with MPA regulations and complement ecological data on potential **spillover effects** where vessels aggregate just outside MPA boundaries (Cope et al. 2022).

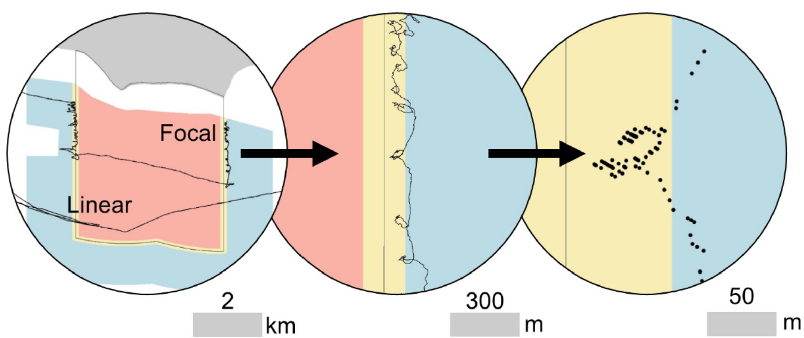


Figure 25: A coastal radar station deployed off southern California (left) and a schematic illustrating representative fine-scale data outputs that highlight alternative fishing vessel behaviours in relation to the boundaries of the Campus Point State Marine Conservation Area (SMCA) MPA (shown in red). Image credits: Protected Seas (left), Cope et al. 2022 (right).

Below the surface, **echosounders** are a type of sonar that has long been used to detect the **depth, size, and biomass** of groups of plankton, fish, or other organisms across broad areas and depth ranges, which can be difficult to accomplish using more traditional capture methods. However, while some acoustic properties of organisms differ between taxonomic groups, it is not generally possible to achieve species-level classification with this type of monitoring (Danovaro et al. 2017). More elaborate multibeam sonar surveys, on the other hand, are typically used to map the bathymetry and geography of the sea floor and broader hydrological conditions, most often used as baseline information for MPAN design (Danovaro et al. 2017).

Passive acoustic monitoring is another existing technology that is more recently being applied in new ways for MPA monitoring to inform management. This method uses one or more hydrophones to listen for sounds associated with both ecological and human activity and can be particularly useful for overcoming limited visibility for visual monitoring (Danovaro et al. 2017, Kline et al. 2020, Stanley et al. 2021). Hydrophones may be deployed in a wide variety of ways depending on the application, ranging from deployment of weighted or moored hydrophones on the seabed, drifting hydrophone buoys, drop deployment alongside a vessel, towed hydrophone arrays, mounted to an remotely operated or autonomous glider, or even mounted onto marine mammals (NOAA 2023).

On the ecological front, hydrophones have long been used to listen for vocalizations by marine mammals, but are more recently being used to characterize the holistic '**soundscape**' of other sound-making or 'soniferous' species as well as environmental events in the surrounding ecosystem (e.g., weather, ice breaking) (Haver et al. 2019). These types of ambient recordings have been used to develop a wide range of marine **ecoacoustic indicators** (reviewed in Minello et al. 2021), including the Acoustic Complexity Index (ACI) which has be used to compare benthic biodiversity inside and outside of MPAs (Davies et al. 2020). Using acoustic data and indicators to monitor changes in soundscapes within and between sites in an MPAN over time can help to provide insights into changes in ecosystem status and composition (e.g., presence and abundance of different vocalizing species) as well as anthropogenic impacts (e.g., vessel noise and potential for masking species vocalizations) to inform marine condition assessment and management (Haver et al. 2019, Reis et al. 2019). For example, hydrophone studies on the Central Coast of British Columbia have documented patterns of anthropogenic noise across Rockfish Conservation Areas (RCAs) and demonstrated that these sounds reach levels anticipated to mask rockfish acoustic communication thought to be important in agonistic and spawning interactions (Nikolich et al. 2021). Importantly, successful interpretation of natural sounds within hydrophone recordings relies on comparison to **biological acoustic reference**

libraries documenting the normal variation in natural acoustic complexity, which are increasingly being developed for hundreds of species and ecosystems at locations all around the world. It is also anticipated that improvements in machine learning technology will accelerate the auto-identification and classification of such sounds using these reference libraries to improve the scalability of these techniques for long-term monitoring (Danovaro et al. 2017, Parsons et al. 2022).

On the human front, passive acoustic monitoring is also increasingly being used as an alternative method for measuring **vessel traffic** in and around MPAs. In this context, hydrophone recordings are analyzed for the number, frequency, volume, and temporal elements of acoustic signals in the recording which can be used to infer **timing, speed, location** and **direction of travel** as well as the **overall duration of vessel noise** in relation to one or more hydrophones (Maxwell et al. 2014, Kline et al. 2020). In order to interpret hydrophone data for position and speed, predictive relationships for sound transmission loss with distance can be developed for each MPA site using patrol boats carrying GPS (Kline et al. 2020). Hydrophone data can also be used to automatically identify and classify **vessel size** and **type** through comparison with existing **vessel acoustic reference libraries** of recordings validated through paired visual observations (Pollara et al. 2017). Importantly, this information can be used to understand presence and activities of vessels in relation to MPA boundaries, particularly for smaller **vessels without automated tracking systems** (i.e., non-AIS vessels, see Remote Electronic Monitoring below), which can make up a significant proportion of all vessel traffic in areas of high recreational marine use and whose noises can dominate marine soundscapes in comparison to larger vessels with tracking systems (Hermannsen et al. 2019, Serra-Sogas et al. 2021). This method can also be used to assess the overall level of **anthropogenic noise pollution** in an area of interest (Burhham et al. 2021), which can mask natural sounds and impede behaviours and processes that depend on acoustic signals, such as echolocation, acoustic communication, and homing of larvae to acoustic signals to find suitable settlement habitat (Bittencourt et al. 2020). In this way, data on underwater noise from passive acoustic monitoring can serve as inputs to **impact assessments** for marine life, for example, by assessing anthropogenic noise production within bandwidths known to disturb or mask vocalizations by marine animals (Stanley et al. 2017, Reis et al. 2019, Hermannsen et al. 2019, Vagle et al. 2021) and inform potential management measures (Joy et al. 2019). Passive acoustic monitoring offers one way to better quantify the holistic activities of all vessels within protected areas and, as with shore-based radar, can be paired with timelapse or motion-activated cameras to provide complementary information on types of vessels contributing to the soundscape and help to build up locally-relevant acoustic reference libraries (Pollara et al. 2017).

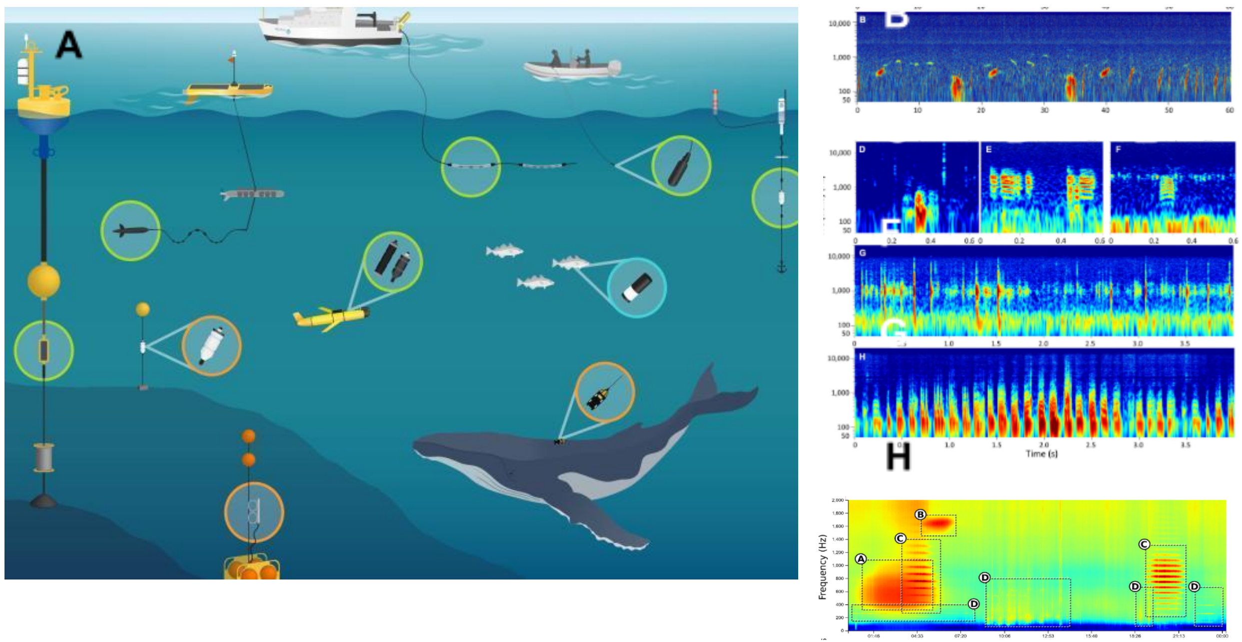


Figure 26: A visual overview of representative equipment and outputs associated with passive acoustic monitoring, including (A) different deployment methods for passive acoustic technology featuring primarily hydrophones, but also showing acoustic animal tags (blue circle, see next section)(Credit: NOAA Fisheries); alongside several examples of the unique spectrogram signatures of different marine animal vocalizations including (B) Humpback Whale (*Megaptera novaeangliae*), (C) gulf toadfish (*Opsanus beta*), (D) sooty grunter (*Hephaestus fuliginosus*), (E) spangled grunter (*Leiopotherapon unicolor*), (F) kina urchin (*Evechinus chloroticus*), and New Zealand paddle crab (*Ovalipes catharus*) (Credit: Parsons et al. 2022). The final panel shows a 24-hour spectrogram including the acoustic signatures of multiple fish choruses (boxed bright red features) as well as multiple ship sounds (boxed pale yellow and green features) (Credit: Reis et al. 2019).

Animal Telemetry

<u>Key Dimensions and Indicators</u>: Ecological (behaviour, distribution, dispersal, connectivity)

At the scale of the organism, telemetry has a long history of use for monitoring the **movement, dispersal,** and **connectivity** of mobile marine animals, including marine invertebrates, fish, reptiles, mammals, and birds (Balbar et al. 2020). This technology relies on the use of electronic tags implanted in or attached to the surface of individual organisms that relay information on their movement and potentially other environmental parameters following release back into the marine environment. A wide range of tag types are available. Smaller passive ratio and acoustic tags that rely on detection by a network of fixed or mobile receivers are less expensive and more suitable for smaller species. However, because they are passive and must be relocated to be read, these tags can require significant sample sizes, numbers of fixed receivers, or roving receiver sampling effort to generate sufficient data for drawing inferences (Balbar et al. 2020). In contrast, larger real-time or archival satellite-linked transmission tags and GPS location tags can auto-upload data and can be used to collect both animal location and additional sensor data on other environmental parameters, but are primarily to track the movements of larger animals (Balbar et al. 2020). All types of telemetry tags are associated with some degree of location error, tagging bias related to deployment locations, and the risk of battery failure or tag loss. These methods also require considerable cost and effort, limiting their use for long-term monitoring studies of species within and across protected areas (Balbar et al. 2020).

However, telemetry studies may still inform MPAN management through the opportunistic use of data from discrete studies that overlap with MPAN locations or intentionally-designed telemetry studies that are tightly scoped to answer key management questions to inform MPAN planning (e.g., by providing baseline data on habitat use and (e.g., adjusting boundaries or allowable activities based on new information on actual habitat use and connectivity following establishment) (Balbar et al. 2020).

Remote Electronic Monitoring

Key Dimensions and Indicators: Ecological (distribution, size, biodiversity), Governance (compliance, management effectiveness)

Remote electronic monitoring (REM) entails the use of satellite, sensor, and sometimes video technology to monitor human activities, typically vessel movements and activities, inside and outside of marine protected areas (Wright et al. 2019, Mack et al. 2020). Positional REM systems allow for monitoring of vessel locations and determining the activities they are engaging in based on their movement behavior in relation to MPA boundaries to assess **compliance** and **management effectiveness** (Maxwell et al. 2014, Iacarella et al. 2023a,b). The two main types of positional systems are Vessel Monitoring Systems (VMS), which are typically used by smaller vessels and often used to monitor fishing activity, and Automated

Identification Systems (AIS), which are mandated by law as a safety measure on large oceangoing vessels such as cargo ships but are also seeing gradual voluntary uptake among smaller vessels (Iacarella et al. 2020).

On some fishing vessels, such as Pacific Canada's groundfish fleet, onboard **Electronic Monitoring Systems** with video cameras are used for visual monitoring of retained and non-retained catch, including as well as handling and releases of prohibited species (Stanley et al. 2015, Beauchamp et al. 2019, van Helmond et al. 2020). Beyond their primary purposes of ensuring compliance with fisheries regulations, data from these systems could be mined for complementary information on **species presence, abundance, size, marine biodiversity, and species associations** in areas outside of MPAs to understand spillover effects and the contributions of MPAs to broader seascape condition (Mack et al. 2020).

However, because these systems require operator agreement for installation, and because they can be turned off to mask illicit behavior by 'dark ships', vessel activity and compliance with MPA regulations is generally monitored through a broader suite of complementary methods that also include shore-based radar or cameras, aerial overflights, and optical satellite remote sensing (Iacarella et al. 2023a). More recently, deep learning approaches have also been used for the automated detection of bearing and speed of marine vessels detected by **satellite-based synthetic aperture radar (SAR)**, a highly accurate method which would help to fill a major gap in the monitoring of vessel traffic for vessels without automated tracking systems (Heiselberg et al. 2023).

Data from electronic monitoring systems is now being packaged into user-friendly **online platforms** that make it easier for managers to apply these tools for the monitoring and management of marine protected areas. For example, the Global Fishing Watch platform aggregates multiple sources of global vessel tracking data in near real time for visualization and analysis of fishing and shipping activities at sea (Kroodsma et a. 2018), while its Marine Manager Portal aims to streamline both environmental and vessel traffic this information specifically for application to marine protected area monitoring and management (GFW 2022). For example, this platform has been used to study vessel traffic patterns indicative of fishing activity in MPAs around the world to demonstrate widespread illegal fishing within many MPA boundaries as well as cases of deliberate disabling of vessel tracking technology to mark illicit activities (Valentine et al. 2022)

Molecular and Cellular Methods

Molecular and cellular methods offer novel ways to directly measure key indicators of MPA effectiveness, particularly biodiversity, connectivity, and ecosystem function, that are difficult to accurately assess by other means. Molecular methods, often referred to as ‘omics’, are generally described as high-thoughput technologies to holistically sequence or quantify organismal or environmental DNA (genomics), RNA (transcriptomics), proteins (proteomics), metabolites (metabolomics), or other molecules (see Jeffrey et al. 2022 for a detailed review).
The implementation of many of these methods in MPA research and evaluation is still in its infancy, but emerging pilot applications are now providing practical guidance for scaling the use of these methods across MPANs, including those being established in large and remote geographic regions (Jeffrey et al. 2022).

eDNA Metabarcoding

Key Dimensions and Indicators: Ecological (species occurrence, biodiversity – methods to detect relative abundance are under development)

Ecological monitoring using environmental DNA (eDNA) metabarcoding is based on the isolation and genetic sequencing of free DNA shed from organisms into the water column or sediment to broadly survey community biodiversity across many taxonomic groups of interest in a rapid, repeatable, and affordable way (Gold et al. 2021, Jeffrey et al. 2022). Environmental DNA methods are well suited to large-scale and intensive monitoring programs, as are often needed for MPAs. They are also particularly advantageous for overcoming common barriers to effective monitoring, for example:

- when low-impact or non-extractive methods are preferred (Pikitch 2018),
- when species are rare, small, or otherwise cryptic, including early arrivals of invasive species as part of biosecurity monitoring programs (Pikitch 2018, Bowers et al. 2021, Carvalho et al. 2023),
- in highly diverse communities of small organisms such as phytoplankton and zooplankton assemblages, including the larval lie stages of many important fish and invertebrate species whose ecology is not well understood, where taxonomic identification to species by visual means is notoriously difficult and laborious (Djurhuus et al. 2018, Smith et al. 2018, Govindarajan et al. 2021), and

- in low-visibility or complex habitats such as eelgrass beds (He et al. 2022), kelp beds (Lana-Wong et al. 2023), and cobble or sediment (Shum et al. 2018) as well as deep ocean habitats (Govindarajan et al. 2021), all of which may be more difficult to survey using visual or capture-based methods alone. Furthermore, eDNA from sediment cores can be used to reconstruct a historical record of both ancient and extant ecological communities from particulate organic matter settling into sediment strata over time which can provide a sense of ecological baselines for MPAs (Deiner et al. 2017).

Pilots to date have demonstrated that eDNA surveys are capable of detecting more species, including rare and threatened species such as Northern Abalone (*Haliotis kamtschatkana*), compared to conventional methods such as seining (He et al. 2022), plankton nets (Govindarajan et al. 2021), or underwater visual census (Gold et al. 2021, Acharya-Patel 2023, Dimond et al. 2023).

The use of eDNA for monitoring ecological indicators can also be far more accessible and efficient than conventional survey methods such as dive-based surveys, which require significant technical training, expensive equipment, and many person-hours to implement at broader spatial scales. In contrast, **eDNA collection by active filtration** can be carried out by diving but also from the surface. Sampling takes place using pumps or 5L Niskin sampling bottles fixed to a weighted line to collect water samples at depth, typically collecting three one-liter samples to improve accuracy. The eDNA is then filtered out of the water using a membrane (via gravity, manual, or electric pump filtration), the membrane is treated to preserve the eDNA, and is finally sent on to a lab for analysis (Gold et al. 2022). This approach has been estimated to take approximately 1/10th of the person-hours at a fraction of the cost per site (~$50/sample) that would be required by diver surveys (Fu et al. 2021, Gold et al. 2021, Dimond et al. 2023), although they cannot provide similar information on size structure, abundance, and habitat characteristics that diver surveys can. More recently, the development and validation of **passive eDNA collection** protocols offers a simpler and more comprehensive alternative. This method involves mounting eDNA filter membranes on a rigid frame that is then submerged the desired sample depth for a set soak time, where ocean currents force water through the membranes to achieve a similar kind of filter-driven eDNA collection (Bessey et al. 2021). More recent studies show that a variety of other filtration materials can provide comparable results (Bessey et al. 2022). The passive approach has been tested in both temperate and tropical waters (e.g., Bessey et al. 2021, Lana-Wong et al. 2023) and shown to yield results comparable to active filtration, further reduces sampling time by eliminating the water filtration step, and offers further advantages in its ability for more comprehensive sampling over a longer timeframe (e.g., up to 48h based on marine eDNA decay rates) (Collins et al. 2018, Bessey et al. 2021), for example, by potentially better capturing different parts of the ecological community active at different times of day within marine protected areas as compared to discrete ‘snapshot’ water samples (Hinojosa et al. 2020). Moreover, the simplicity of eDNA sample collection methods makes them **well suited for monitoring programs involving community or citizen science partners**, especially over many sites across large and remote regions where distributed monitoring effort will be required. Examples include organizing a citizen science eDNA Marine “BioBlitz” across Denmark (Agersnap et al. 2022), and self-directed eDNA sampling by volunteer family groups across the Japanese archipelago using standardized kits following virtual training and including reporting of results back to participants (Miya et al. 2016 and 2022; Suzuki-Ohno et al. 2022).

More recently, technological advances are now allowing ***in-situ*** **molecular sensors** originally designed to measure, preserve, and in some cases even analyze genetic data from microorganisms in near real-time are being adapted to study a wider range of organisms using eDNA (Deiner et al. 2017). Improving compatibility of these sensors with other marine technologies like remotely operated or autonomous underwater vehicles will soon also further expand the ability for targeted sampling of eDNA across a much wider range of depths and habitats (Spanbauer et al. 2020).

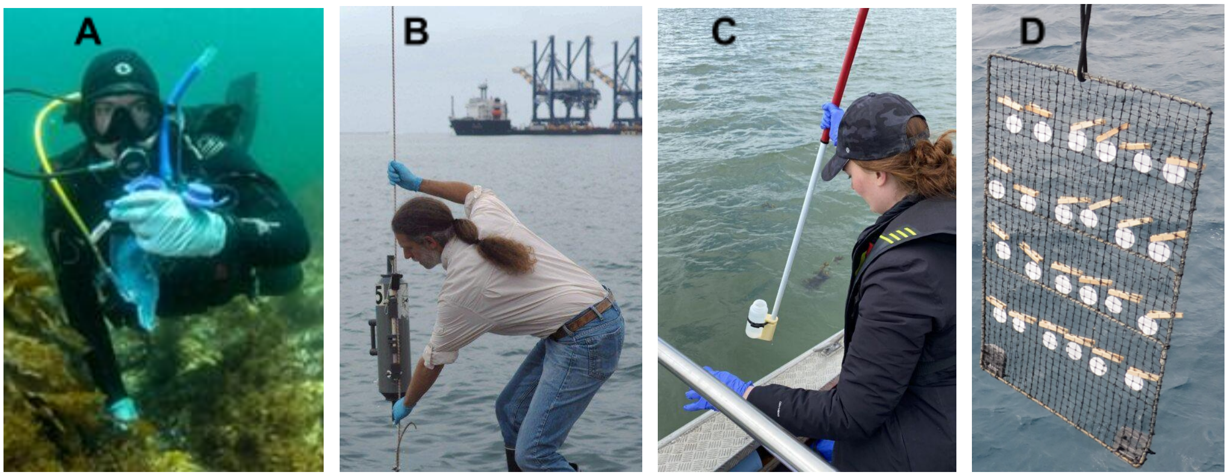


Figure 27 Four methods of collecting eDNA water samples via (A) SCUBA diving or (B), Niskin sampling bottle deployed on a weighted line for sampling at depth, (C) Nalgene bottle deployed on a pole for sampling in shallower water, and (D) filtration membranes mounted on a frame deployed at depth for passive eDNA sampling. Photo credits left to right: Gold 2018 / ReefCheck, Janie Chen / Natural History Museum of LA, OceanWise, Bessey et al. 2021.

Incorporating eDNA monitoring into a long-term monitoring program requires the development of reference libraries of genetic primers specific to the taxonomic groups or species of interest. While assays are generally available for identifying broad taxonomic groups such as whales, rockfish, and decapod crustaceans (e.g., Komai et al. 2018, Andruszkiewicz et al. 2020), reference libraries for key focal taxa may not yet be available in the area of interest for monitoring. Depending on the level of taxonomic resolution desired, additional work may be needed to develop additional molecular targets capable of differentiating closely related species within an assemblage, such as rockfish (Acharya-Patel 2023).

Although most applications of eDNA to date have been limited to the measurement of species richness, work is underway to develop more reliable methods for **quantitative eDNA metabarcoding** capable of providing information on relative abundance or biomass of the species of interest (Rourke et al. 2022). Multiple studies have established that eDNA detection probability and concentrations are positively associated with biomass estimated through conventional methods (Rourke et al. 2022), including seine netting (e.g., for fish communities within eelgrass beds, He et al. 2022), diver surveys (e.g., for Northern Abalone, Dimond et al. 2023), and plankton tows (Ershova et al. 2021). The sensitivity of these assays has also been shown to increase by a significant margin (30-90%) when using newer droplet digital PCR (ddPCR) compared to quantitative PCR (qPCR) technology (Dimond et al. 2023).

As the use of eDNA technology becomes more widespread in MPA contexts, specific **eDNA-based indicators** are being developed and validated as alternative ways to measure MPA effectiveness. For example, eDNA-based measures of **functional diversity**, **phylogenetic diversity**, and the **ratio between demerso-pelagic and benthic species richness** were found to be responsive and reliable early indicators of MPA effectiveness in the Mediterranean Sea that can complement more conventional methods and indicators (Dalongeville et al. 2022, Sanchez et al. 2022). Concurrently, best practices are also emerging for improving the useability and accessibility of marine environmental eDNA data outputs, including standardization of methods and terminology, complete metadata, supplementary methods, and open access (Shea et al. 2023).

Population Genetics

Key Dimensions and Indicators: Ecological (dispersal, connectivity, gene flow)

Population genetics methods are based on sampling the genome of many individuals of a species across one or more sites to draw inferences about population structures and processes both within and across sites (Balbar et al. 2020). Population genetic information can be logistically challenging to collect, but is one of the few quantitative means of evaluating network effects across multiple MPAs including monitoring genetic population **connectivity** and structure, and studying **recruitment** and **dispersal** patterns through parentage and sibship analyses, and identifying new migrants (D'Aloia et al. 2017, 2019).

These questions can be answered using direct or indirect methods. Indirect methods such as calculation of **isolation-by-distance relationship (IBD)** assume that populations are more genetically distinct over greater geographic distances, and the rate of genetic divergence over distance can be used to calculate dispersal distances to estimate the spatial scales of genetic connectivity to inform the spatial scale of monitoring (Balbar et al. 2020). Direct methods make fewer assumptions and can help to answer different management questions, but typically require much more intensive sampling that is only feasible at smaller spatial scales. **Parentage**

and relatedness analysis, also known as close-kin mark recapture (CKMR) can help to quantify potential benefits of MPANs beyond their borders by measuring **self-recruitment** within MPAs and **spillover effects** across MPA boundaries (LePort et al. 2017, Sinclair-Waters et al. 2018, Baetscher et al. 2019, Jeffrey et al. 2022). However, these methods require genetic sampling of both parents and potentially thousands of offspring over multiple age classes and multiple years (Jeffrey et al. 2022). For example, sampling 4,000 individual Australasian snappers (*Chrysophrys auratus*) inside and outside a single MPA in New Zealand was required to establish that adults within it contributed 10% of juveniles found in the area surrounding the MPA (Le Port et al. 2017), and sampling of 15,000 individual rockfish was required to identify just eight parent-offspring pairs and 25 full-sibling pairs to establish a spillover effects across a network of marine reserves in central California (Baetscher et al. 2019). Moreover, parentage and relatedness analysis only yields information about movement when sampling occurs over short timeframes, whereas estimates of gene flow require more continuous sampling across the geographic range of interest to understand whether offspring are also reproducing following dispersal (Gagnaire et al. 2015, Balbar et al. 2020).

At broader population scales, population genetic diversity and parentage analysis can also be used to estimate trends in effective population size and absolute abundance as well as quantify adaptive variation to assess vulnerability to specific pressures, such as size-selective fisheries harvest or climate change, or to detect the genomic signatures of evolutionary selection in response to those pressures (Xuereb et al. 2021, Jeffrey et al. 2022). Insights from methods such as these can help to inform more proactive management action to improve the likelihood of meeting MPA management goals and objectives in the context of broader environmental change.

Epigenetics and Transcriptomics

<u>Key Dimensions and Indicators</u>: Ecological (organism health), Governance (Management effectiveness)

Beyond the genome itself, emerging methods focused on monitoring changes in gene expression can be used to detect organism and population-level responses to ecosystem stressors inside and outside of MPAs (Jeffrey et al. 2022). Changes in gene expression can be quantified through whole-genome sequencing to analyze epigenetics, the presence of molecular markers such as methyl groups or histones that become associated with certain regions of the genome in response to different environmental conditions and determine whether genes are switched on or off in those conditions as part of an adaptive response. Changes in gene expression can also be quantified further ‘downstream’ by measuring the amount of RNA produced during transcription of a given gene through RNA sequencing or transcriptomics (Jeffrey et al. 2022).

These methods can be used to assess the expression of stress-related genes at multiple scales of organization both inside and outside of MPAs to understand whether pressures are being effectively reduced through protection. For example, one study demonstrated that the expression of stress-related genes associated with responses to high contaminant levels were higher in crabs outside than inside an MPA of interest (Baratti et al., 2022). There is also growing interest in environmental RNA (eRNA) approaches to monitoring overall health and stress response across the broader ecological community (Yates et al. 2021).

Geochemical Methods

Geochemical methods rely on natural variation in the concentration of elements across abiotic and biotic marine habitats to make inferences about the ecology of organisms associated with those habitats. These methods can provide unique insights into habitat associations and food webs across both time and space that are difficult to quantify through other methods. However, both geochemical tags and spatial isotope analysis require invasive physical sampling and rely on extensive baseline studies to establish patterns of variation in chemical signatures within the broader environment and understand their relationships to variation observed in the organisms of interest (Balbar et al. 2020).

Geochemical Tags

Key Dimensions and Indicators: Ecological (distribution, dispersal, behaviour)

Environmental heterogeneity in marine systems is often reflected in the physiology of organisms in ways that produce a long-lasting biological record in the form of a **geochemical signature or ‘tag’** in an organism’s tissues or body structures (Balbar et al. 2020). The geochemical composition of calcified structures of marine organisms, such as the shells of invertebrates or the otoliths (ear-bones) of fish, are influenced by the presence of trace elements in the surrounding seawater which vary regionally and are deposited in these structures as they form.

For example, the elements strontium and oxygen are known to be closely associated with transitions across salinity and temperature gradients, respectively.

The relationship between this variation and physiological response can thus be used to identify the association of organisms with specific environments over time and space (Balbar et al. 2020). Because calcified structures are formed layer by layer over days or years, like tree rings, studying the way geochemical signatures change across layers through laboratory analysis can provide a record of ambient conditions across an organism's lifetime to help answer questions about their **habitat preferences, distribution, dispersal, and connectivity** across time (e.g., life stages) and space (e.g, MPANs and the border marine seascapes around them) (Balbar et al. 2020). For example, geochemical methods have been used to distinguish between spatially segregated populations of a species (e.g., inshore and offshore) or identify the relative composition of different populations or spawning groups when sampled as part of a mixed stock (Stanley et al. 2016). They can also be used to understand the migration of organisms across different key habitats across their life cycle and ensure these habitats are well connected and represented across MPANs (Balbar et al. 2020). Geochemical tags have also been used to demonstrate MPA **spillover effects** when the chemical environments inside and outside MPAs are sufficiently different (Legrand et al. 2019).

Importantly, the utility of this method depends on the resolution of environmental variability in the geochemical elements used as tags and on baseline studies to establish the relationships between these conditions and corresponding geochemical signature levels in organisms. Environmental variation tends to occur at coarser scales in open marine environments compared to more confined terrestrial environments, but may still prove informative over the larger scales of an MPAN if it matches larger scale processes of interest for management (Balbar et al. 2020). Because geochemical signatures form naturally, they also provide an efficient alternative to mark-recapture studies relying on artificial physical tags which can be resource-intensive and impractical over very large scales (Balbar et al. 2020).

Stable Isotopes

Key Dimensions and Indicators: Ecological (distribution, dispersal, behaviour, ecological process connectivity, food web dynamics/trophic level), Governance (pressures, management effectiveness)

Similar to geochemical analysis, stable isotope analysis (SIA) takes advantage of variation in the ratios of isotopes for some elements such as carbon, nitrogen, and sulfur across different types of primary producers (e.g., phytoplankton, eelgrass, kelps) at local to regional scales, which are then concentrated or 'enriched' across increasing trophic levels of consumers across the food chain. Laboratory analysis of stable isotopes in tissue samples can be used to answer questions about habitat associations, diet, movement, and energetic transfer pathways across food webs in ways that are relevant for the management of MPANs and broader seascapes (Balbar et al. 2020, Mack et al. 2020).

Stable isotopes have been used to determine the **site fidelity** or **movement** of organisms in relation to one or more specific habitats and latitudinal ranges (Balbar et al. 2020). Stable isotopes can also be used to monitor changes in marine food web dynamics associated with ecosystem recovery following protection in MPAs to track effectiveness and performance over time. For example, studies have suggested that **consumer niche widths** (Olson et al. 2019) or **food web length and stability** (Mack et al. 2020) may be an early signal of broader prey availability and increasing food web complexity while changes in **mean trophic level** (Blanco et al. 2021) may signal the recovery of predators that were previously harvested. Stable isotopes can also be used to monitor **human-associated pressures** in the form of nitrogen and carbon inputs into the marine environment, for example, through runoff of fertilizers or human and animal waste that are taken up by phytoplankton, seaweeds, and marine plants and contribute to marine eutrophication (Mack et al. 2020, Franklin et al. 2020).

As with geochemical tags, the utility of this method depends on baseline studies to establish a sufficient range of predictable variability of isotopes across different food sources, habitats, and environmental gradients to define unique 'iso-scapes', as well as understanding tissue- and species-specific isotope turnover rates, to interpret the results of analyses (Balbar et al. 2020).

2.6.3 Monitoring and Sampling Design

Successfully interpreting the data emerging from MPA monitoring programs to draw valid inferences about MPA effectiveness that can inform decision-making hinges on a robust sampling design, particularly in the more complex context of MPANs composed of multiple sites that vary in their characteristics and environmental conditions (Thiault et al. 2019, Perkins et al. 2021).

Selecting a Suitable Sampling Design

Many approaches to sampling design exist depending on the type of monitoring question of interest, ranging from **knowledge development questions** that investigate status, to **data mining questions** that aim to identify trends or relationships within and between parameters of interest, to **causal questions** that aim to understand what factors are actually driving the trends observed in monitoring data (Hayes et al. .2015). Importantly, not all monitoring designs are able to successfully answer all types of questions, and monitoring programs that aim to establish the effectiveness or 'impact' of a management intervention, such as establishment of a MPA or MPAN, meant to inform decision making require a higher standard of statistical rigor to establish a causal relationship between intervention and outcomes (Ahmadia et al. 2015, Kupschus et al. 2016, Hayes et al. 2019, Wauhchope et al. 2021). A recent review of key types of monitoring designs for a marine context provides a helpful guide for understanding the evidence hierarchy associated with different types of monitoring designs and their suitability for answering the different types of monitoring questions (Hayes et al. 2019). Within this framework, it is generally understood that management decisions often require the highest strength of evidence possible to justify the potential trade-offs of the management action in terms of lost economic or other opportunities.

Among common sampling designs, **randomized controlled studies** are acknowledged to provide the greatest strength of evidence for making causal inferences, followed by **non-randomized controlled trials**, case-control or cross-sectional studies, uncontrolled studies, and finally expert opinion (Hayes et al. 2019).

Randomized controlled trials include several types of study designs such as **before-after-control-impact (BACI)** studies, and cross-over studies, but with the requirements that sample units are **randomized** (or randomly allocated to either the control or intervention groups) and **spatially balanced** (evenly spread over the distribution of the parameter of interest) to help increase the likelihood of a **representative** sample (one that is representative of the whole population of interest) and minimize the effects of confounding variables (see next section for more information). In the contexts of MPANs, **before-after-control-impact paired series (BACIPS)** are a suitable variation that tracks change across multiple pairs of sites over time. However, both BACI and BACIP designs assume a rapid step-change from before to after conditions, which are unlikely to occur in an MPA context where change is expected to accrue more gradually and follow more complex dynamics given the long lifespan of some species and the sometimes staged progression of enforcement and compliance. The newer

Progressive-Change BACIPS design provides a more flexible approach that can detect and quantify additional patterns of temporal change (e.g., linear, asymptotic, and sigmoidal) (White et al. 2011, Thiault et al. 2019).

Although these types of statistically rigorous sampling designs are increasingly being incorporated into MPA monitoring and evaluation frameworks, they remain rare, potentially due to the widespread lack of **baseline data** to inform these studies (Thiault et al. 2019, Hayes et al. 2019). 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 more typically takes place within the first few years following implementation of zoning and management plans (Ahmadia et al. 2015, Hayes et al. 2019, Thiault et al. 2019, van Digglen et al. 2022). This generally precludes the use of before-after sampling designs, which greatly reduces the ability to draw inferences, further stressing the importance of baseline data collection prior to establishment. In some cases, baseline information is already available for some indicators that are collected through existing monitoring programs. However, gaps are likely to remain, particularly given that those programs were likely not designed with MPA effectiveness evaluation in mind (Ahmadia et al. 2015).

Controlling for Confounding Variables via Sampling Design

Controlling for confounding variables is usually done through careful matching of treatment and control sites, randomization and higher sample sizes, spatially-balanced sampling designs, or through a combination of these approaches (Hayes et al. 2019).

Randomization and Increasing Sample Size

Randomization involves selecting sample sites from within control and intervention sites randomly from across the population of the parameter of interest makes it more likely that the overall sample, across all sites, will be representative of the population and will reflect the different combinations of influencing or confounding factors other than the treatment. These benefits or randomization are more likely to emerge with **larger sample sizes** (Hayes et al. 2019). There are generally logistical and cost constraints to the number of sampling sites possible within an MPA monitoring program, and tools like power analysis (see sections below) can be used to check the size of the sample for a given sampling design and frequency that is needed to detect changes in the parameters of interest, or otherwise predict how long it will take for monitoring to detect change for a given sample size (Perkins et al. 2021).

Randomized studies are not always possible in an environmental context for a variety or reasons. In some cases, this is because the distribution of many ecosystem pressures and management interventions is non-random (e.g., the location of fishing, sewage outfalls, MPAs, etc.) (Hayes et al. 2019). However, statistical matching methods that aim to randomize the selection of control sites can be used to approximate fully randomized study designs and increase statistical rigor (see below, Ahmadia et al. 2015). In other cases, full randomization may not be appropriate given the monitoring question of interest. For example, when monitoring sessile species like cold-water corals or sponges, **fixed transects** will allow better detection of trends in relative abundance, while **random transects** are more likely to capture impacts from localized stressors (e.g., fishing due to noncompliance), such that a mix of both sampling strategies may be most appropriate (Loh et al. 2019). In other cases, this is a result of poor weather conditions, equipment failure, and other unpredictable elements of field logistics, resulting in unintentionally unbalanced samples and uncontrolled confounding factors. In light of this reality, monitoring strategies should plan ahead to apply more sophisticated statistical methods, such as generalized linear mixed effects models with spatial and spatiotemporal random fields, that are capable of making robust inferences despite these irregularities (Anderson et al. 2022, Thompson et al. 2022b).

Careful Selection and Matching of Treatment and Control Sites

Ongoing monitoring at **control or reference sites** carefully matched to environmental conditions within MPAs can provide a functional baseline for ongoing comparison with MPA sites to test the **counterfactual** (e.g., changes in fish populations that would have occurred without protection) as part of a long-term MPA evaluation program (Ahmadia et al. 2015).

Because MPA sites are usually intentionally placed across a seascape to meet a set of social, ecological, and management objectives, reference or control sites are often assigned using **manual or statistical matching** methods in an attempt to ‘reverse engineer’ a randomized controlled trial design meant to minimize observable bias (i.e., differences between MPA and control sites arising from non-random assignment). Such methods may use a tiered approach, where coarse manual matching based on habitat mapping and expert knowledge is first used to generate a list of candidate reference areas thought to be most comparable to MPA sites, followed by statistical matching using statistical software to generate sets of MPA and reference sites through randomization within MPA areas and coarse matching areas to match similar conditions of selected influencing factors or covariates of MPA performance (e.g., matching to sea surface temperature, exposure, substrate type, distance to key habitat types, fishing and pollution risk, using the Matching package in the R statistical software suite, Ahmadia et al. 2015). Additional **constraints** may need to be added to matching algorithms to account for other factors of interest for evaluation. For example, by imposing a rule to select matching reference sites within a biologically meaningful dispersal distance (e.g., 5 - 10 km) from an MPA boundary to facilitate the detection of spillover effects (Ahmadia et al. 2015), while forcing the inclusion of legacy sites can help to maintain the link to historical context through long-term time series (Przeslawski and Foster 2020). For example, lightstations that have long housed long-term marine monitoring instruments could be included as legacy sites for environmental monitoring designs to take advantage of existing time series for key indicators at these sites and promote the co-location of additional monitoring at these existing sites.

Ultimately, matching must balance trade-offs between the **quality of matches** (i.e., minimizing differences in covariates across pairs, which may vary by covariate) and the number of possible control sites, which affects **sample size** and thus the ability of post-hoc analyses to detect changes in MPA outcomes. Importantly, post-hoc analyses will also need to account for any remaining biases following matching (Ahmadia et al. 2015, Hayes et al. 2019).

Spatially Balanced Sampling

Selection of sampling sites can be further constrained by drawing from a **master sample frame**, a set of standard sampling points spread across the entire region of interest for an overarching monitoring purpose (e.g., MPAN evaluation), from which sub-samples can be drawn to meet the needs of different monitoring activities and programs (e.g., monitoring designs for specific indicators) (Stein and Lacket 2012, van Dam-Bates 2017). Master sample frames can be developed using different methods and software tools (see Box 3), and they are particularly helpful when coordinating monitoring activities across multiple programs or organizations.

Spatially-balanced techniques for creating master samples are particularly desirable (van Dam-Bates 2017, Hayes et al. 2019). These techniques involve selecting sample sites that are evenly spread over the distribution of the parameter or indicator of interest, with not many clumps or empty areas in the distribution of sample sites. This can help to increase the likelihood that areas which may contribute more uncertainty to population estimates will be samples (van Dam-Bates 2017, Hayes et al. 2019). When randomization is used without considering spatial balance, there is a chance that random sites will all be clustered in one area with similar environmental influencing factors. However, spatially balanced sampling can be used with randomization as randomization can be constrained to choose random sites within a specific sample frame – e.g, selecting random sites only within protected areas, areas where specific habitats occur, areas accessible by communities, or other criteria (Hayes et al. 2019).

Spatial, Temporal, and Scale Considerations

The accuracy of MPA effectiveness evaluation based on comparisons between monitoring data before or after protection and inside and outside of protected areas can be further confounded by the **spatial and temporal scales** of monitoring. For example, the responses of multiple dimensions and indicators being monitored can be influenced by **MPA size, pre-establishment fishing effort, time since establishment, levels of effective protection, and the dispersal distances, connectivity, generation time, and history of harvest** of key species (Moffitt et al. 2013, Claudet et al. 2017, Thiault et al. 2019, Li et al. 2020, Loiseau et al. 2021). Modelling using methods such as generalized linear mixed effects models (GLMMs) with spatial and spatiotemporal random fields can be used to assess the relative influence of these factors and identify general rules of thumb for conditions under which the greatest changes are expected (e.g., more than two dispersal units away from MPAs following two generations) which can inform more rigorous sampling designs that account for these factors (Moffitt et al. 2013, Anderson et al. 2022, Thompson et al. 2022b).

Box 3: Master Sample Frames for Marine Monitoring

Several methods of creating a master sample exist for environmental monitoring contexts, each with benefits and drawbacks (van Dam-Bates 2017):

- **Generalised Random Tessellation Stratified (GRTS):** selects a systematic sample from an ordered population of sites, such that any contiguous subsample of sites in the sample will still be spatially balanced. GRTS designs are usually oversampled to create more sampling sites than initially needed to add more sites if required. However, once the oversample is chosen, it is not possible to generate additional points.
- **Local Pivotal Method (LPM):** More spatially balanced than GRTS, but does not include an ordering strategy for the set of sampling sites it generates so it is not suitable for oversampling and subsampling.
- **Balanced Acceptance Sampling (BAS):** Generates a set of spatially balanced and hierarchically ordered sampling points similar to GRTS, but is more flexible because it uses a random-start number sequence approach that generates an infinite number of possible sample sites, so that the oversample can be adjusted with additional sites.

Software tools exist to help managers develop sampling designs that meet these sampling criteria for their own monitoring or study contexts. Three relevant and recent software packages designed for this purpose for the R statistical software suite include:

- **MBHdesign**: Short for 'Marine Biodiversity Hub design', this R package was developed as a tool for developing efficient spatially balanced and randomized sample designs for point or transect monitoring of study sites. It can also select transects to start at the same origin or specifically cover a gradient of specific variable (e.g., depth). Importantly, this tools allows users to generate these designs while **incorporating existing "legacy" monitoring sites** from existing monitoring programs to help build out from existing work. This package was designed for and has been used in planning monitoring programs both tropical and temperate sites (many including kelp) for the Australian Marine Protected Area Network (Foster 2020, 2021).
- **Emon**: Short for 'environmental monitoring', this R package was developed to support the design of marine ecological and environmental studies, surveys and monitoring programmes. This package focuses on understanding the level of statistical power to detect effects based on sample sizes and designs through power analysis functions that tell managers the sample sizes needed to detect specific features or trends (Barry et al. 2017).
- **BASMasterSample**: This R package was designed to select sample sites from a Master Sample using the balanced acceptance sampling (BAS) method. The default is to select a Master Sample from Canada's Western Marine Master Sample, but it can also be used with other sample frames (van Dam-Bates 2017, R Package Documentation).

As data accumulate to generate long-term **time series data**, some additional considerations are warranted to minimize the potential for misleading results. These include considerations about the following temporal parameters (Thiault et al. 2019, Wauhchope et al. 2021):

- **metric of change** you are most interested in (e.g., comparing the **average** value of an indicator across the time series or the **trend** in that indicator across the time series) (Wauhchope et al. 2021);
- **timeframe** of response you are expecting or interested in (e.g., immediate response right at or after implementation of the intervention based on life history characteristics such as generation time or growth rates of focal organisms, where slower growing or longer lived species can be expected to have longer response times, which can help to determine appropriate monitoring frequencies) (Moffitt et al. 2013, Loh et al. 2019, Kaplan et al. 2019, Wauhchope et al. 2021);
- **pattern of change** (e.g., step-change, linear, asymptotic, or sigmoidal) (Thiault et al. 2019);
- controlling for effects such as **zero values** or **time lags** in the analysis, which are influenced by expected response times, to reduce the potential for misleading results (Wauhchope et al. 2021).

Importantly, these considerations apply to both the **change expected following MPA establishment** and the natural variability in the **indicator of interest** (e.g., natural peaks and troughs in recruitment rates) and **other environmental variables** (e.g., severe environmental disturbances) which can otherwise temporarily obscure or negate the effects of protection. These factors should be explicitly accounted for during both sampling design and the analysis of monitoring data (Thiault et al. 2019, Hopf et al. 2022c).

Finally, in the context of MPANs, the use of consistent, **standardized** monitoring, indicators, and nested sampling designs across MPA sites and partner organizations will facilitate data interoperability, aggregation, and reporting at multiple spatial and temporal scales (Buck et al. 2019).

Assessing Statistical Power to Detect Change

The ability of different monitoring indicators, methods, and sampling designs to yield robust inferences can be tested prior to implementation using various forms of **power analysis**. When monitoring is occurring in the context of MPANs, resource constraints will require managers to make trade-offs between available monitoring methods, levels of within-site sampling, and levels of spatial and temporal replication achievable across multiple MPA sites within the network (Perkins et al. 2021).

Power analyses involve the use of models that can simulate expected changes in MPA indicators and assess the ability of different sampling design elements such as sampling effort, size, location, and frequency for different indicators, methods, and initial conditions (e.g., pre-implementation level of fishing mortality influencing starting fish densities or recruitment rates) to determine which combinations are best able to detect changes in the parameters of interest across an MPAN (Nickols et al. 2019, Perkins et al. 2021). Such performance testing can also be projected forward to estimate of the **duration of sampling required** to signals of change in parameters of interest against the noise of their own variability and background environmental variation under different conditions, which can be critical to help **set realistic expectations** for the detection of signals of ecosystem recovery among MPA managers and partners (Perkins et al. 2021, Brown et al. 2023). Validating proposed MPAN sampling designs in this way helps to identify shortcomings and make **adjustments** prior to modifying existing monitoring programs (Lloyd-Jones et al. 2022) or embarking on the implementation of new time- and resource-intensive monitoring programs which may not otherwise yield the desired return on investment (Perkins et al. 2021). For example, an inability to increase sample sizes to detect changes more quickly can be offset by incorporating more **early indicators** anticipated to respond more quickly to protection (Walker et al. 2012, Kaur et al. 2020, Jaco and Steele 2020), or by **pooling data** across species or sites (Caselle et al. 2015, Caselle and Cabral 2018)

Adapting Monitoring Designs to Practical Constraints

Resources for monitoring are often limited, requiring programs to scale monitoring to align with available logistical, financial, and personnel capacity for both data collection and analysis (Gill et al. 2017, Milosavich et al. 2019, Benway et al. 2019). A number of strategies to address these challenges by scaling monitoring efforts in different ways have emerged through research and professional practice and allow for the flexibility of ramping up monitoring to take advantage of periods when resources are more abundant (CDFW and OPC 2018, Pickard et al. 2019):

- **Indicator priority**: There may be a variety of indicators which help to answer a particular big question (e.g., sea surface temperature and temperature at depth). The cards rank these in terms of priority. **Core indicators** should always be collected. **Secondary** indicators should be collected where capacity allows or based on local priorities. Commitment to consistent long-term monitoring of core indicators can be supplemented by data from periodic short-term projects (Plisnier et al. 2018).

- **Tiered monitoring designs**: Tiers of monitoring differ in terms of their capacity requirements with lower tiers being simpler or more cost-effective cheaper strategies and higher tiers being more intensive and often more costly in exchange for producing higher-quality data (e.g., Thompson et al. 2021). Monitoring designs may be tiered by *type or complexity of monitoring method* (e.g., fisher dependent vs. fisher independent surveys of catch), or by *tiers of monitoring sites* classified according to different levels of priority (CDFW and OPC 2018).
- **Sampling effort**: refers to the frequency of sampling in space and time, which can be scaled using methods such as *stratification* (e.g., where sampling sites are chosen from within subgroups of the overall population that have shared characteristics) or the more statistically rigorous use of *altered inclusion probabilities* in balanced sampling, rotating panel designs (e.g., where sites are revisited periodically according to a set schedule rather than every month or year) (Przeslawski and Foster 2020) as well as *nested sampling designs* that explicitly consider variability in processes across multiple spatial scales (e.g., at within-site, site, and network scales) where sampling is structured) (Lasiak 2006, Harmelin-Vivien et al. 2008).

Importantly, 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 staff turnover. These data collection methods should include both backwards-looking (e.g., capturing historical knowledge through interviews, traditional use surveys, or 'ride-alongs' of elders with Guardian staff for insights into baselines and trends over time for specific indicators and sites) and forward-looking elements (e.g., capturing new knowledge through culturally-aligned data collection methods and activities to understand current status and trends). For example, opportunistic data on the presence, absence, and condition of kelp around MPA sites can be used to ground-truth remote sensing observations, while data on the size of fish collected by community members in the course of routine fishing activities around the boundaries of MPAs can be used to supplement size data collected by stewardship technical staff using structured dive surveys or baited underwater video stations.

2.6.4 Standardization and Coordination of Monitoring

Regional MPAN monitoring programs that involve the collection of many types of data by many different partner organizations, standardization, coordination, collaboration, and integration are essential for ensuring that monitoring data is collated, synthesized, and translated into forms that are relevant and usable for evidence-based decision-making (Lemos et al. 2012, Pelletier et al. 2020).

Standardization monitoring protocols are crucial to improve data interoperability and facilitate monitoring coordination as well as data aggregation across sites within the network, which will be needed to understand the effectiveness of the network as a whole (Buck et al. 2019). Many MPAs and MPANs have issued standard monitoring and evaluation protocols to meet this need (e.g., for Australia in Przeslawski et al. 2019, and New Zealand in New Zealand Government 2022), while additional best practices for standardization are also being developed for emerging monitoring technologies (e.g., eDNA in Shea et al. 2023 and underwater video monitoring in Pelletier et al. 2021) and marine data management workflows (e.g., Buck et al. 2019, Neang et al. 2020, Thomer et al. 2020). These resources provide helpful guidance for others seeking to develop standard protocols of their own. However, standardization of all forms of data collection may not always be feasible or appropriate. 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 (Parlee et al. 2021). In cases where standardization of methods is not practical, it is also possible to implement standardization at the data analysis stage for methods that have different biases and tradeoffs, for example, by applying correction factors (e.g., for known differences in selectivity and detection probabilities) when aggregating data (Frid et al. 2021).

Once standardized methods are established, close **coordination** among partner organizations involved in monitoring. Coordination is necessary at multiple tiers of the science to management continuum to ensure that (1) monitoring activities are occurring efficiently in time and space, (2) that the right streams of data are integrated to answer specific monitoring and management questions, and (3) and that the resulting information and knowledge products reach the right tables to inform decision-making (**Figure 28**).

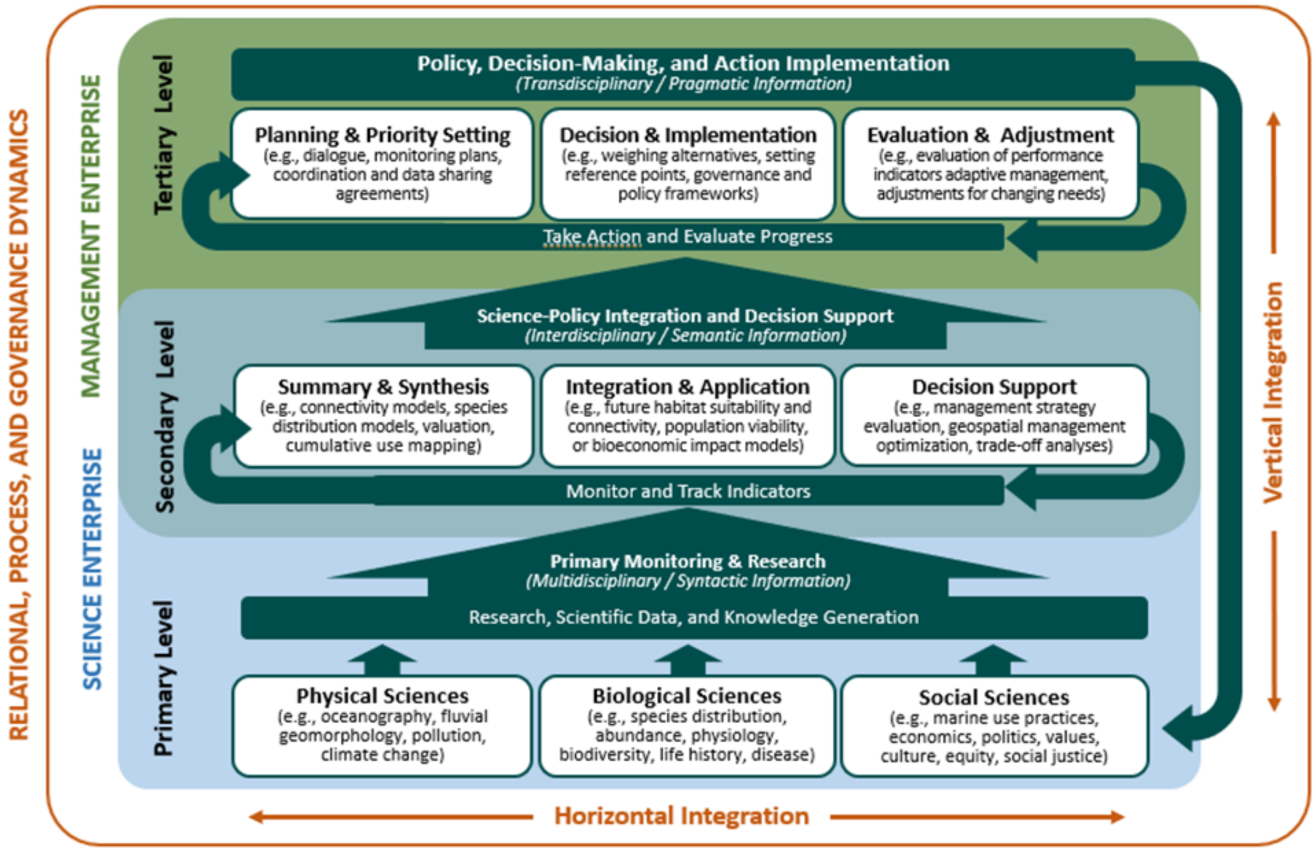


Figure 28: A framework for knowledge integration across the science to management continuum with examples from the context of MPAN monitoring and management. Activities within each level of knowledge production contribute to higher levels of knowledge synthesis and decision-making, and the quality of 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. Adapted from Eddy et al. 2014.

Coordination of monitoring activities begins by building partnerships with other organizations, sectors, or communities engaged or planning to engage in complementary monitoring activities to build trust and understanding of common monitoring and management objectives (Carr et al. 2011, Read and West 2014). Coordination of monitoring activities themselves involves a collaborative crosswalk across monitoring designs and methods for each indicator or parameter of interest across each monitoring program to understand overlaps in focal indicator, technology, platform, time, and space. The intent 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 (Danovaro et al. 2017, Ehrman et al. 2022).

For **coordination of data integration, analysis, and reporting**, managers are advised to work backwards 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 to 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. Importantly, smooth information flow along this pathway is contingent on the broader socio-ecological context in which they are embedded, including the individual and organizational relationships, trust, behaviours, processes, politics, and values that influence and enable information flows and integration across these activities. Cultivation of these **enabling factors** can be a lengthy process, but failure to do so can lead to breakdown of information flow that hinders evidence-based decision-making.

2.7 Data Management

Data management for marine protected area networks entails several core components that collectively influence how data is collected, organized, used, shared and maintained over time, while also ensuring adherence to legal requirements and best practices for data privacy and confidentiality. In general, it is recommended that marine protected area authorities adhere to FAIR data standards by ensuring that data is findable, accessible, interoperable, and reusable (Coché et al. 2021; Schoening et al. 2022). However, when working with First Nations, it is also important to be attentive to principles of First Nations data sovereignty by addressing issues concerning ownership, control, access, and possession of data. For example, the analysis and representation of data collected by or about Indigenous communities 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 (e.g., Frid et al. 2021).

FAIR data standards are a set of principles for promoting transparency and use of data by ensuring that data is findable, accessible, interoperable, and reusable. These principles were developed in response to the increasing amount of data being generated in scientific research, and the need for better ways to manage and share that data. The FAIR data principles are designed to promote data sharing, collaboration, and reproducibility in scientific research. By making data more findable, accessible, interoperable, and reusable, researchers can more easily build on each other's work, leading to faster progress and more impactful discoveries. Definitions and high-level guidance for the four principles of FAIR data are outlined below.

- **Findable:** Data should be easy to find for both humans and machines, with clear and accurate metadata that includes information about the data's source, its creators, and the ways it is intended to be used
    - F1. (Meta)data are assigned a globally unique and persistent identifier
    - F2. Data are described with rich metadata (defined by R1 below)
    - F3. Metadata clearly and explicitly include the identifier of the data they describe
    - F4. (Meta)data are registered or indexed in a searchable resource
- **Accessible:** Data should be accessible, with clear and consistent licensing and usage rights that allow for reuse and redistribution.
    - A1. (Meta)data are retrievable by their identifier using a standardised communications protocol
        - A1.1 The protocol is open, free, and universally implementable
        - A1.2 The protocol allows for an authentication and authorisation procedure, where necessary
    - A2. Metadata are accessible, even when the data are no longer available
- **Interoperable:** Data should be interoperable or more generally it should be structured and formatted in a way that allows for easy integration with other data sources and analysis tools.

    - I1. (Meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation.
    - I2. (Meta)data use vocabularies that follow FAIR principles
    - I3. (Meta)data include qualified references to other (meta)data
- **Reusable:** Data should be reusable, meaning it should be well-documented and preserved over time, and made available in a way that allows for its reuse by others.
    - R1. (Meta)data are richly described with a plurality of accurate and relevant attributes
        - R1.1. (Meta)data are released with a clear and accessible data usage license
        - R1.2. (Meta)data are associated with detailed provenance
        - R1.3. (Meta)data meet domain-relevant community standards

It is important to consider Indigenous rights and Indigenous leadership on how data and information are managed. The First Nations Information Governance Centre (FNIGC), which was first established in 1998 and registered as a non-profit in 2010, to respond to gaps in Canadian laws, policies and society regarding the rights of Indigenous communities to information about themselves and the lands and resources for which they are stewards. In the past, First Nations were rarely consulted by external researchers from universities and government agencies regarding the purpose and design of research, the types of question they would ask and their alignment with the interests, needs and values of First Nations, and how they could access and use this information for their own purposes. As a result over time FNIGC developed a set of principles, known as OCAP®, that provide guidance with respect to ownership, control, access and possession of data that help to ensure that information is used and shared in ways that maximizes benefits to a community, while minimizing harm. The OCAP® principles as outlined by the FNIGC are outlined as follows:

- Ownership refers to the relationship of First Nations to their cultural knowledge, data, and information. This principle states that a community or group owns information collectively in the same way that an individual owns his or her personal information (FNIGC 2023)
- Control affirms that First Nations, their communities, and representative bodies are within their rights to seek control over all aspects of research and information management processes that impact them. First Nations control of research can include all stages of a particular research project-from start to finish. The principle extends to the

control of resources and review processes, the planning process, management of the information and so on (FNIGC 2023)

- Access refers to the fact that First Nations must have access to information and data about themselves and their communities regardless of where it is held. The principle of access also refers to the right of First Nations' communities and organizations to manage and make decisions regarding access to their collective information. This may be achieved, in practice, through standardized, formal protocols (FNIGC 2023)
- Possession While ownership identifies the relationship between a people and their information in principle, possession or stewardship is more concrete: it refers to the physical control of data. Possession is the mechanism by which ownership can be asserted and protected (FNIGC 2023)

In practice, data management involves standardized processes, dedicated roles, and documented workflows to ensure that raw data collected through monitoring programs is iteratively and successfully translated into data products that are centralized, accessible, and relevant to end users (**Figure 29**, Buck et al. 2019).

For example, in the UK data management and guidance for the Marine Strategy and other marine related commitments is administered by the Marine Environmental Data and Information Network (MEDIN). MEDIN was initially established in 2008 using an open partnership model with the aim of ensuring adherence to best practices for collection, analysis, management, reporting and sharing of data (Jolly et al. 2021) and to date includes information on over 17,000 marine datasets. MEDIN provides tailored guidelines for data that should be collected across 40 different types of data related to marine bathymetry, physical oceanography, marine geology, human impacts, marine chemistry, marine archaeology and marine biodiversity to ensure that adhere to relevant standards and that they can be used in the future. Importantly MEDIN has served an important role with respect to reporting for the UK Marine Monitoring and Assessment Strategy (UKMMAS) by enabling the use of existing data and data collection programs wherever possible to establish baselines and realize efficiencies.

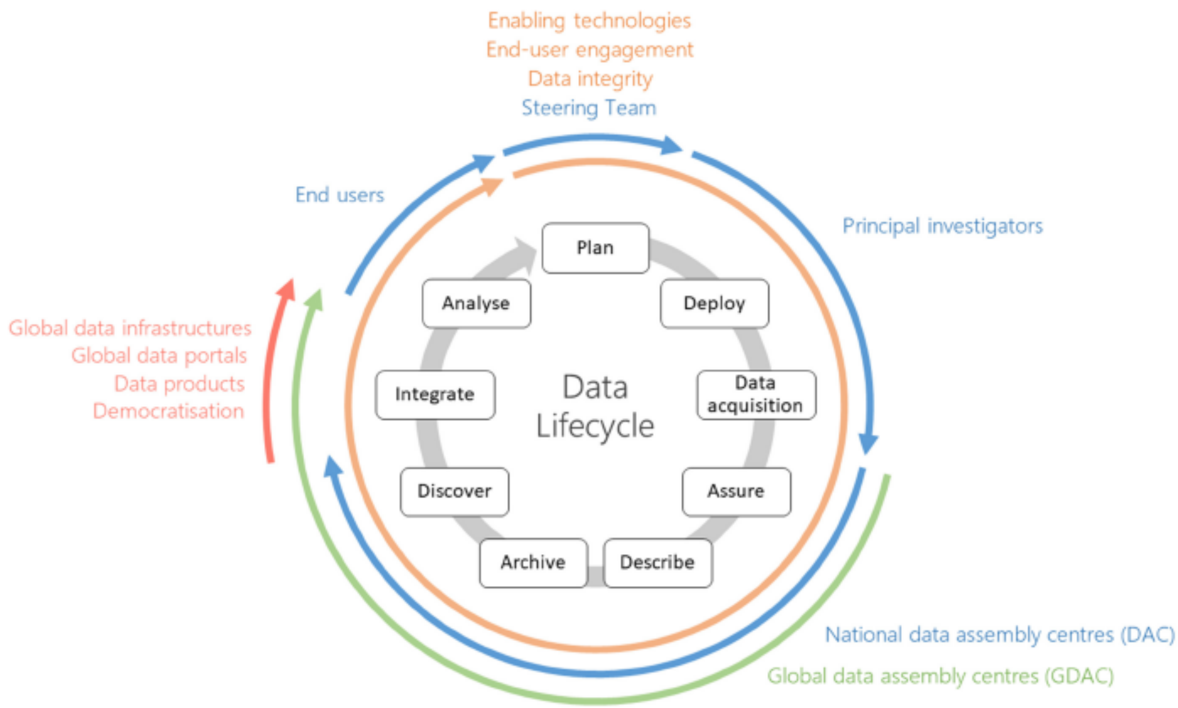


Figure 29: Roles and processes involved in the data life cycle associated with any monitoring and evaluation program (Reproduced from Buck et al. 2019).

2.8 Analyses and Evaluation

Common Analytical Tools and Models for MPAN Evaluation

The translation of monitoring data to indicator status and trends for the purpose of evaluation may be simple, using aggregation through **summary statistics**, **hypothesis testing**, **correlation**, and **time-series trend analysis** or more complex, where monitoring data are used as **inputs to models** that generate predictions of the emergent properties of MPANs and potentially project them forward through time to generate testable hypotheses (Pelletier et al. 2008, Addison et al. 2018). Many of these tools are the same ones used in MPAN planning, but are updated with new data collected following MPA establishment in an iterative cycle where new empirical monitoring data can also help to continually **validate** and adjust models to improve their performance (Pelletier et al. 2008).

The integration of data with a broad toolbox of statistical and dynamic models is particularly important for the evaluation of MPAN processes and outcomes at spatial and temporal scales and resolutions which would be difficult to achieve directly through monitoring alone (Pelletier et al. 2008, Addison et al. 2018). For example, long-term monitoring data on juvenile recruitment can be used as inputs to **habitat and population connectivity models** to assess how connectivity may be changing over time in response to protection and other factors like climate change (Carr et al. 2017, CDFW and OPC 2018). Similarly, monitoring data on environmental conditions and adult species distributions are often used to develop **species distribution models** that can be used to track changing habitat suitability across MPANs at multiple spatial and temporal scales to evaluate species representation (Friesen et al. 2021). As noted earlier in this report, robust monitoring and sampling designs can also support analyses to **distinguish the causal mechanisms of change** in one or more indicators and identify theoretical reference points based on causal relationships (Pelletier et al. 2008, Addison et al. 2020, Frid et al. 2021). By their very nature, the evaluation of MPANs also requires analysis and reporting at multiple scales to assess **whether the whole is greater than the sum of its parts**. This approach seeks to test the hypothesis that the magnitude or effect size of key objectives and response indicators (e.g., greater biomass of focal species inside than outside of MPAs) at the scale of the network (i.e., biomass both inside and outside MPAs) is greater than the sum of magnitudes of change occurring in individual MPAs (Grorud-Colvert et al. 2014).

Historically, the assessment of data for different dimensions of reporting (e.g., environmental, ecological, social, and governance) have occurred in silos, or have focused primarily on comparing empirical data on ecological outcomes to community perceptions of those outcomes to look for divergence (e.g., Richter et al. 2022). However, there are increasing calls for fully **integrated assessment of holistic socio-ecological systems** that use monitoring information as inputs to **end-to-end models** such as Ecopath, Atlantis, or POSEIDON that explicitly model relationships between indicators, assess the outcomes of current management, and evaluate future management scenarios (Addison et al. 2018, Tam et al. 2019). For example, baseline and ongoing monitoring data on human use in and around MPAs can be used to calibrate models of social behaviour among fishers in response to different MPA size, area, or zoning configurations as part of the POSEIDON end-to-end model (Bailey et al. 2018, Burgess et al. 2020). Beyond adjustments to sampling design, the use of **multimodel ensembles** and **model averaging** to answer monitoring questions can also help to reduce uncertainty by balancing sources of bias across different types of models (Addison et al. 2018).

Data Integration and Aggregation Considerations

In the context of MPANs, there will also be a need for different types of **data combination, integration, aggregation, and rollup** to make inferences using multiple sources of evidence about effectiveness across multiple dimensions, indicators, sites, and spatio-temporal scales of an MPAN and **facilitate transparent and comprehensible reporting** to communities, partners, and policy-makers (Barnard and Strong 2014, Thiault et al. 2019).

However, integration can be challenging when regional-scale monitoring programs include data collection over multiple scales, degrees of continuity, and data collection methods. This is likely to occur when integrating data from previously existing monitoring programs initially designed for other purposes, seeking to reconcile data from institutionally led and citizen science monitoring programs, or integrating environmental, social, and economic data types (Maas-Hebner et al. 2015, Addison et al. 2018, Becken et al. 2019).

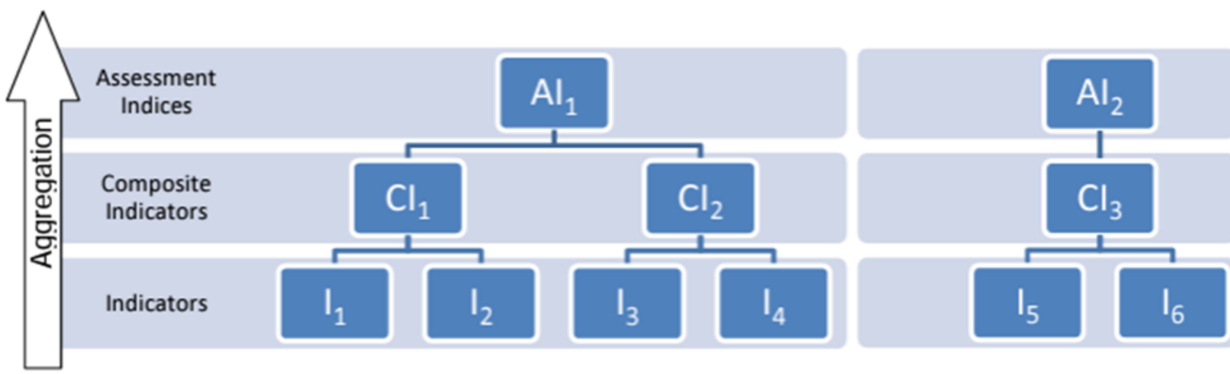


Figure 30: Schematic of different levels of aggregation across indicators, where these tiers of aggregation may also occur within and across spatial and temporal scales (Reproduced from Barnard and Strong 2014).

As a result, it is important for this step to take into account the following **best practices for statistically-sound data aggregation** to maintain the validity and reliability of assessments across scales, including (Barnard and Strong 2014, Maas-Hebner et al. 2015):

- **Defining well-articulated monitoring questions** for aggregate analysis and hypotheses at multiple scales of organization that specify the target population(s) and sample frames of interest.

- **Identifying interoperability issues**, including data consistency and quality within individual datasets and indicators as well as mismatches in data comparability, sample size, sample effort, and spatial or temporal coverage between datasets. *Comprehensive metadata records* capturing the characteristics of various data collection efforts are essential for this purpose.
- **Identifying and reconciling issues with statistical aggregation**, including pseudoreplication, spatial autocorrelation, cross-scale correlation, and unknown confounding variables or 'lurking' variables that may be introduced when multiple related datasets at multiple scales are combined for analysis. Notably, many marine ecosystem indicators respond differently when analyzed at different scales, and managers are advised to conduct sensitivity analyses by investigating indicators and relationships at multiple spatial scales to make stronger inferences (Heim et al. 2021). These issues should be reconciled using appropriate statistical techniques such as weighting, post-stratification, transformation, calibration, and the inclusion of spatially varying coefficients in subsequent analyses and modelling (e.g., Thorson et al. 2023). Similar reconciliation may be needed before aggregating data collected by different methods with different biases and tradeoffs (e.g., by developing equations for standardizing data that account for factors such as differing detection rates and selectivity across methods, as in Frid et al. 2021). Selection of the most appropriate method is influenced by monitoring context and whether the samples being combined are both probability-based, which is more straightforward, or not, which gives rise to further issues.
- **Carrying out aggregation,** using the most appropriate techniques including both qualitative (e.g., conditional rules) and quantitative (e.g., averaging, multi-metric indices, or multivariate analyses) each associated with their own advantages and disadvantages for different marine data types (reviewed in detail by Barnard and Strong 2014).

These considerations should be **incorporated from the early 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 (Maas-Hebner et al. 2015). For example, combining data from different studies is much more straightforward when standardized sampling methods are used and sampling designs are both probability based, and particularly if sampling sites were chosen from the same master sample (Maas-Hebner et al. 2015, van Dam-Bates et al. 2017, Wicquart et al. 2022). 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 (e.g., Barnard and Strong 2014, Wicquart et al. 2022).

Assessing and Communicating Uncertainty

Despite their many advantages, many models used for the strategic planning and assessment of MPAs and MPANs make a number of **assumptions** about the socio-ecological systems they aim to reflect. These might include assumptions of homogenous age structures or larval distributions, endpoints reflecting long-term steady state rather than short-term variability, omission of bioenergetics or evolutionary adaptation, and linear responses, among others (White et al. 2011). These assumptions are each associated with a degree of uncertainty that should be quantified, propagated through the models and data aggregation steps and, acknowledged and clearly communicated as caveats to inferences drawn by any given analysis, a best practice which very few marine socio-ecological modelling studies currently meet (Addison et al. 2018).

When faced with multiple sources of evidence and uncertainty about the relative weight of evidence of each of those sources, the literature offers several frameworks that can be used to **evaluate the amount, quality, and consensus of evidence** (e.g., Burkhardt-Holm and Scheurer 2007, Mastrandrea et al. 2011, Bates et al. 2014). This information is then combined into a **confidence score**. For example, in cases with low-quality information (e.g., indirect accounts or anecdotal evidence) but a large volume of evidence that all agrees, it would still be possible to have high confidence in the conclusions. Likewise, high-quality data with less volume (i.e., fewer sites) may still be considered high confidence. 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 (Pickard et al. 2019).

Capacity Constraints on Analysis and Evaluation

Capacity for data management and analysis can often be the most limiting factor in distributed monitoring programs involving partnerships with local communities. This barrier can be overcome with **training and capacity-building** activities to establish dedicated capacity for analyzing MPA monitoring data. However, there is growing interest in the use of **digital data entry** (e.g., using mobile apps and tablets) as well as **automated scripts, workflows, and intuitive web-based platforms** for rapid processing standardized MPA monitoring data and generating outputs to reduce barriers to analysis associated with the need for complex technical knowledge of statistical tests and software (e.g., Pelletier 2020 in R, Faro et al. 2017 via the web-based R shiny app MAREA). 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 interface for indicator analysis, and dashboards of indicators were cited by participants as among the most valued practical outcomes (Pelletier et al. 2020).

2.9 Communications and Reporting

Ongoing understanding, trust, and support are imperative for achieving best outcomes following the establishment of an MPAN because partners and the broader public often play key roles in monitoring, compliance, and enforcement. A public engagement and communications plan with regular reporting intervals has thus been identified as an essential element of broader monitoring and evaluation plans as a means of cultivating and maintaining this ongoing trust and support. 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.

Communications plans for MPAN monitoring and evaluation should also address strategies for crafting and delivering messages based on the specific context of MPANs themselves - for example:

- 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 **setting realistic expectations** for the timeline and magnitude of anticipated benefits, which can be influenced by factors such as prior harvest pressure, natural recruitment variation, time since MPA establishment, and others (Nickols et al. 2019). 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. These predicted outcomes can help to provide context for the communication of evaluation results to the broader public, as evaluation is most effective when it is possible to determine whether and how the protected areas are achieving anticipated outcomes.

- Because many aspects of MPAN performance on multiple indicators will be assessed using highly 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 (e.g., CEC 2011, Brown et al. 2019, Spector et al. 2021, Benson et al. 2021).
- Importantly, a communications plan should account for the communication needs and preferences of different audiences, which may require different messaging and modalities. For example, the Australian Institute of Marine Science has assembled helpful lessons learned on 'closing the circle' by returning knowledge to the country through sharing monitoring results across generations of Indigenous Traditional Owners using a wide range of accessible and culturally appropriate communications strategies, each of which have their own pros and cons (AIMS 2021).

2.10 Pathways to Management Decisions

A global review found that only 13% of MPAs actively use the results of monitoring programs to inform management, often due to capacity constraints (Gill et al. 2017). 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. Adaptive management emphasizes the complex and dynamic nature of ecosystems and the importance and value of continuous learning and adjustment based on monitoring and responding to social and ecological feedbacks (Walters 1997; Rist et al. 2013; Nickols et al. 2019; Grorurd-Clovert et al. 2021). As such it is important to design monitoring and evaluation programs to enable managers and partners to quickly identify knowledge gaps and emerging threats and develop plans for addressing them.

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 (Tony 2020). 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 (Nickols 2019, Tony 2020). 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.

There is a need to include indicators relevant to management both **within** and **outside** protected areas. 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.

Adaptive management is generally enabled from the adoption of SMART objectives, which are goals that are specific, measurable, achievable, relevant, and time-bound. It is worth noting that although there is a clear relationship between indicators and objectives or goals, setting of objectives or groups should generally precede indicator selection to ensure alignment between those indicators and the interests, needs and values of partners (Beliaeff and Pelletier 2011). Although it may be possible to define indicators based on other MPAs or MPANs, or by drawing upon the knowledge of experts, neglecting partners, stakeholders, and rights holders in objective setting and indicator selection can undermine long-term conservation objectives. Nonetheless, adherence to the general principles of SMART objectives may facilitate adaptive management in a variety of different ways.

- Objectives that are **specific** generally enhance prospects for adaptive management by clarifying the components of systems for which outcomes are expected and the nature or direction of these outcomes. For example, the UK marine strategy establishes 11 core descriptors of Good Environmental Status, including cetaceans, fish, seabirds and benthic habitats and generally seeks to maintain or improve the status of those descriptors.
- Objectives that are **measurable** provide insights about the status and trends of outcomes relative to objectives to facilitate reporting and adaptive management. While measures are often quantitative in nature, providing insights about the distribution and abundance of different species, or concentration of contaminants; qualitative measures

can also be particularly useful to generate insights about perceptions, mechanisms and unexpected impacts. For example, monitoring for the California MPAN incorporated focus groups which allowed them to explore how commercial fishers were impacted by the synergistic effects of the MPAN and COVID-19 pandemic. Measurable objectives can also be used to develop management triggers that define points at which specific management actions (i.e., change in rules) or general actions (i.e., organize a meeting) are made (Nie and Schultz 2012). However, none of the reviewed cases appear to have established strict thresholds or triggers for management action apart from reviewing strategies following regular reporting schedules.

- Objectives should be **achievable** or realistic by taking into account available resources and constraints. For MPANs this generally means taking into account the timeframes for which outcomes might reasonably be expected to develop, and the extent to which management actions within the network have the potential to deliver outcomes. More specifically ecological and environmental outcomes can take years or decades to be realized (Kaplan et al. 2019) and hence it is important to set realistic expectations, identify intermediate outcomes (i.e., halt declines in fish biomass) and identify leading indicators directly tied to management actions (i.e., reduced bycatch, increased compliance). Further, while management actions in MPANs are generally designed to improve outcomes, such as increased biomass, sometimes the drivers of those outcomes extend beyond the scope or scale of an MPAN. Migratory species, for example, pose unique challenges and hence require some adjustments beyond raw reporting of abundance to capture management effectiveness. Additionally, marine monitoring and evaluation programs are increasingly facing challenges with respect to isolating the effects of marine policy and management from the effects of climate change. In the UK, managers have aimed to isolate management effects on the breeding success of Kittiwake by comparing observations to a baseline estimate derived from a model predicting breeding success on the basis of sea surface temperatures. Finally, as the time between management actions and expected outcomes increases, it is generally beneficial to include layers of short, medium and long-term objectives to provide leading indicators of outcomes and detect emerging threats. Pressure monitoring is particularly salient in this regard by allowing managers and partners to monitor changes in short-term outcomes such as bycatch or compliance that are likely to contribute to long-term outcomes such as abundance and distribution of species.

- Objectives should be **relevant** in that they are directly aligned with high-level goals and objectives and useful for managers and partners to inform adaptive management. At a minimum, most objectives should be designed to provide insights as to the current status or conditions of some feature or attribute relative to some baseline or threshold, and/or report trends with respect to that feature or attribute to highlight items that may require further attention. For example, the UK marine strategy assesses the current status of indicators against indicator specific benchmarks (where available) and their trends to develop a dashboard that highlights areas that may require changes in management measures. Where possible it is also helpful if a subset of indicators and/or data collection methods are specifically designed to offer insights as to the nature of changes that might be required to achieve objectives. The Oregon MPAN, for example, collected data regarding the motivations for tourist visits which could be used to inform promotion strategies targeted investments in tourist infrastructure.
- Objectives should be **time-bound** in that time horizons are clearly defined and deadlines are established to ensure results of monitoring and evaluation can feed into a regular adaptive management cycle. Reporting on progress is required every ten years in California and Oregon, and every six years in the United Kingdom, providing an important opportunity to revisit strategies and consider opportunities for improvement. However, although regular reporting and adaptive planning is generally conducive to long-term adaptive management, it is also important to create opportunities for managers and partners to detect and respond to rapid changes in indicators that fall outside of regular reporting intervals.

Conclusion

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.

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Appendix A: Workshop Report - Synthesis of Best Practices and Procedures for Operationalizing MPAN Monitoring

Quadra Centre, Quadra Island, BC
2 February 2023

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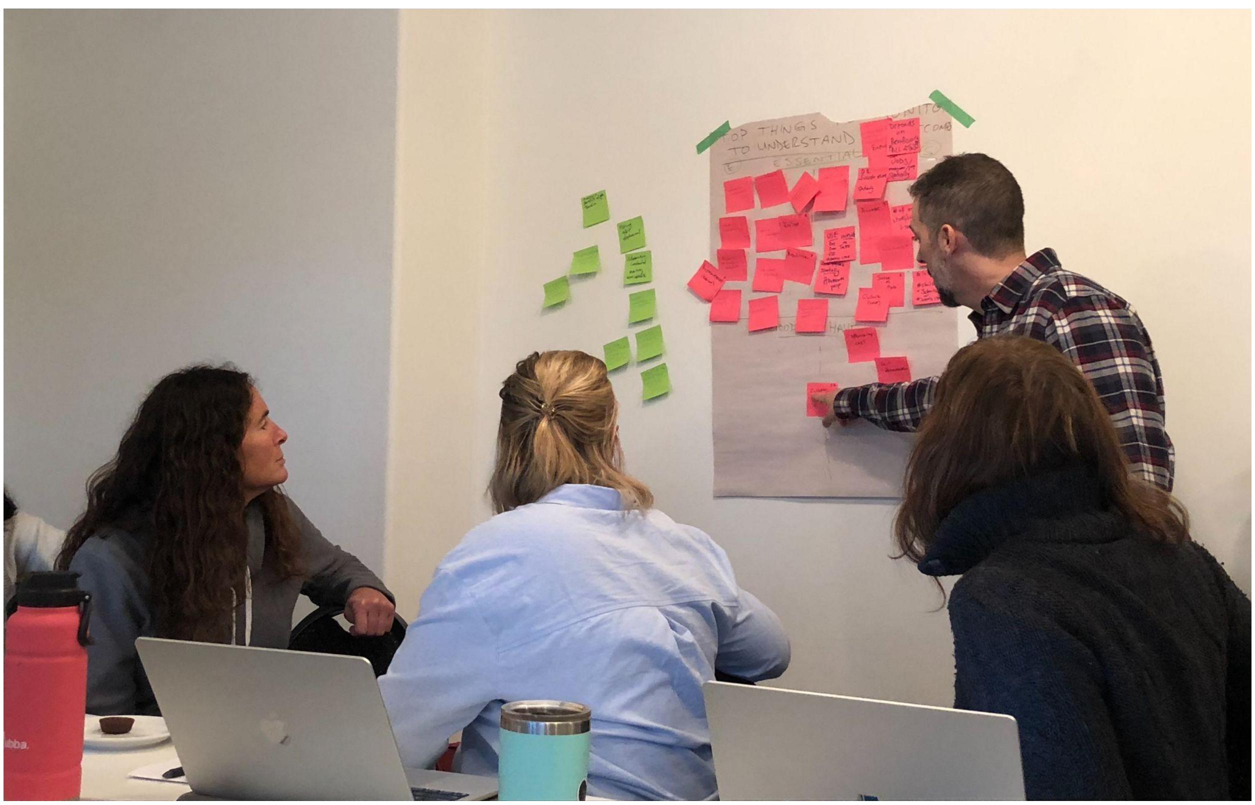
Workshop Purpose

As part of the approach to building this report, the consulting team was invited to facilitate a half-day workshop at the Quadra Centre, BC as part of ongoing engagement with experts with knowledge of MPAN monitoring. The objectives of the half day workshop were to: (1) identify relevant literature and resources related MPAN monitoring, (2) synthesize insights into means of monitoring linked social-ecological dimensions for MPANs, and (3) distill key considerations for monitoring the proposed Northern Shelf Bioregion (NSB) MPAN. The experts who participated in this workshop (Table 1) were convened for a larger three day retreat that was aimed to advance thinking towards ways that MPAN monitoring programs can conceptualize and assess linked social-ecological outcomes. This broader retreat was organized and facilitated by Natalie Ban[6], with early planning stages supported by Luisa Ramirez.

This workshop report provides an overview and summary of main outcomes of discussions. Through the half day workshop, the group of experts helped to identify important social and ecological dimensions to measure for MPANs, linkages among those dimensions, as well as key considerations for the NSB monitoring program.



[6] A workshop report for the broader report is also under preparation. For more information contact Natalie Ban (nban@uvic.ca).

Table 1: List of workshop participants in alphabetical order.

Name, Organization	**Title**
Lindsay Aylesworth, Oregon Department of Fish and Wildlife	Marine Reserves Program Leader
Dana Baker, Marine Ethnoecology Lab, University of Victoria	Postdoctoral Fellow
Natalie Ban, School of Environmental Studies, University of Victoria	Professor
Jenn Burt, Nature United	British Columbia Marine Program Lead
Mark Carr, Department of Ecology & Evolutionary Biology, University of California, Santa Cruz	Professor
Joachim Claudet, French National Centre for Scientific Research	Senior Researcher
Arielle Levine, Department of Geography, San Diego State University	Professor
Rebecca Martone, Tula Foundation's Ocean Decade Collaborative Center for the NE Pacific	Executive Director
Mairi Meehan, Ocean Frontier Institute (Dalhousie University)	Postdoctoral Fellow
Luisa Ramirez, Policy and Economic Branch, Fisheries and Oceans Canada	Social Scientist
Emily Rubidge, Institute of Ocean Sciences, Fisheries and Oceans Canada	Research Scientist
Anne Salomon, School of Resource and Environmental Management, Simon Fraser University	Professor
Anna Schuhbauer, Fisheries Economic Research Unit, University of British Columbia	Research Associate

Outline of Activities and Questions

To begin the half day session, the consulting team presented background information about the proposed MPAN in the Northern Shelf Bioregion (NSB). This information included an overview of the proposed area, the types of protected areas that will be part of the network, the governance partners, the status of planning efforts, and key expected social and ecological outcomes of the network. The team also presented a set of brief case studies of how monitoring has been planned and carried out in other MPANs, including California, Australia, New Zealand, and Scotland / UK to help seed discussion.

Following this presentation and discussions that addressed participants' questions, participants were split into three groups for breakout discussions. The breakout groups were asked to discuss three questions:

1. What are the top things to monitor in order to understand social-ecological outcomes for a MPAN?
2. Ecological and human dimensions indicators are often measured and reported completely separately. How could the linkages between these features and their indicators be more meaningfully monitored and evaluated?
3. What stands out for you as particularly important for monitoring the BC MPAN?

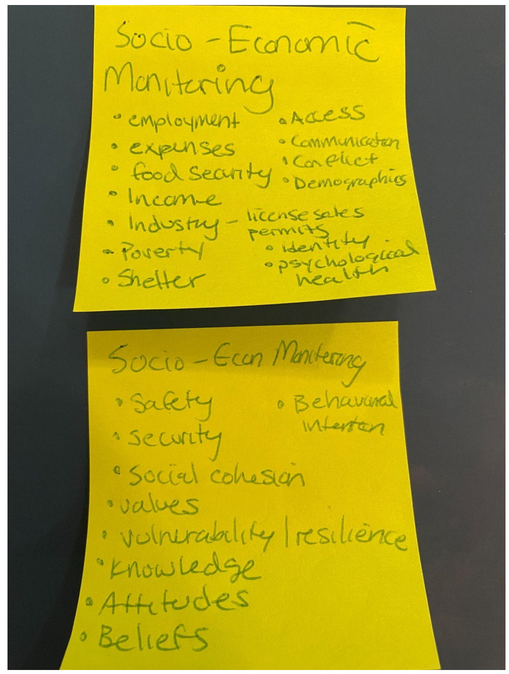
Each of the breakout groups were led by one of the facilitators (Natascia, Mark, and Jenn), who guided the discussion and documented ideas on sticky notes and flipcharts. Following breakout group discussions, the groups came together again for plenary discussion. This final discussion focused mainly on the final question. While the summary of outcomes and insights below was derived from notes about all of the breakout discussions, this workshop report emphasizes synthetic insights from the final question.

The consulting team is grateful to the participants for their contributions to the discussions that led to the insights summarized below. We note, however, that the points raised in this report may not reflect the views of all participants. Responsibility for this synthesis lies ultimately with the consulting team.

Summary of Outcomes and Insights

Following the workshop, the consulting team compiled all notes, which included highlights from each breakout group (sticky notes and flipchart notes) as well as notes taken by the facilitation team. The following summary reflects the facilitators' synthesis of eight key insights generated by participants' discussions.

1. Monitor Social and Ecological Indicators As Linked Dimensions



Workshop participants discussed the importance of seeing social and ecological domains as linked and interconnected. Breakout groups began by thinking about individual indicators and metrics to measure. The lists in Table 2 are not exhaustive but provide an overview of potentially important dimensions to measure. There was also recognition that resources for monitoring are always limited - it is impossible to measure everything - and participants frequently mentioned 'key' species, 'key' habitats, and other species or dimensions that may be seen as culturally important. In plenary discussion, participants advocated to think beyond seeing *social* and *ecological* as separate boxes - there is opportunity for NSB to monitor in innovative ways with appropriate planning and foresight. As there was broad recognition of the importance of linkages, participants quickly shifted towards thinking about metrics that may help to understand relationships between indicators at a network scale. Consideration should be given to identifying suites of indicators that have multiple uses, cover values and processes that are expected to respond more and less quickly to MPA establishment, balance trade-offs between monitoring pressures versus outcomes, and have potential for contributing to monitoring and understanding of broader cumulative effects within the region.

Table 2: Examples of potential socio-economic and ecological dimensions to monitor.

Socio-economic	**Ecological**
Economic stability (resource and value) Fishing Catch Per Unit Effort (CPUE) Fishing effort displacement Compliance Opportunity (access, rate of use) Protection (heritage and archaeological resources)	Recruitment Age, size structure of key species Abundance of key species Biomass Diversity Ecological function (proxies of productivity, connectivity)

Perceptions of trust, transparency, conflict Sense of place Cultural values, identities Safety (fishing, tour boats) Employment Food security Self determination Food, Social, and Ceremonial (FSC) catch for First Nations as an attribute (are you meeting your subsistence needs?) Youth engagement in stewardship	Habitat attributes Percent cover of biogenic habitats Representativeness across the network Climate variables

2. Causal 'Chains' of Related Social-ecological Indicators

The facilitators presented the idea of using causal chains as a way of moving beyond thinking of ecological and social indicators separately and instead thinking about relationships and dependencies among indicators and broader network-wide outcomes. As depicted in Figure 1, a core idea of using causal chains is to think in terms of "benefit-relevant" indicators, where improvements in ecological indicators at the start of the chain yield benefits for the ecosystem services and, ultimately, the social values that rely on them. Benefit-relevant indicators aim to capture emergent benefits for ecosystem services that have a direct influence on social values, as values themselves can be more difficult to measure. This idea coincides well with another point expressed by participants about the importance of participatory monitoring processes and aligning indicators with the interests of local First Nations rightsholders and other stakeholders.

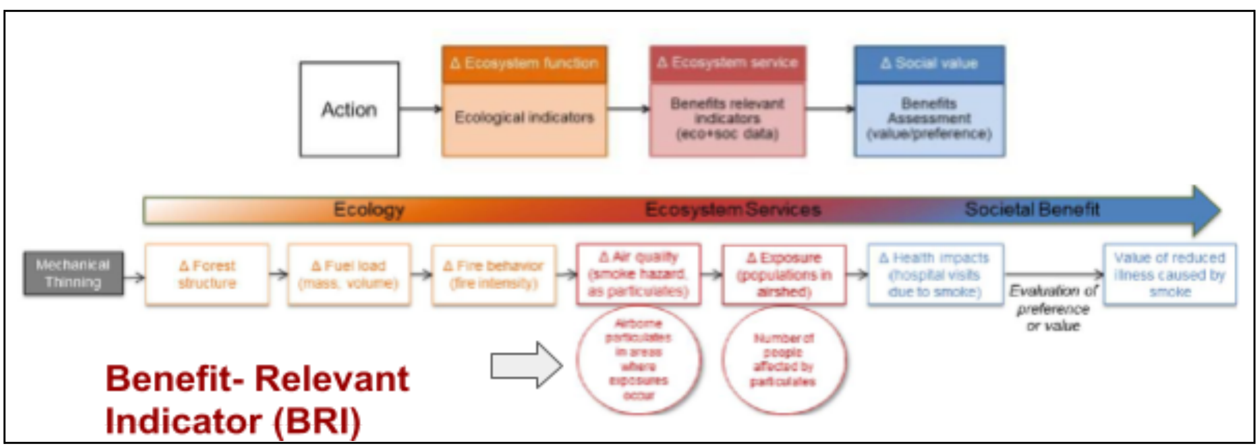
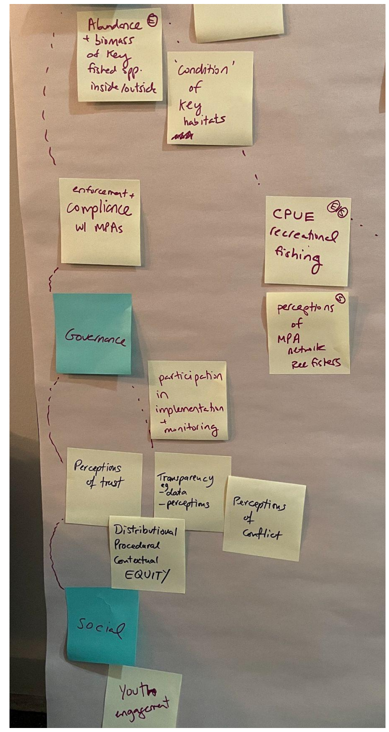


Figure 1: Schematic of causal chains of indicators and benefit-relevant indicators. *From* Olander, L.P., Johnston, R.J., Tallis, H., Kagan, J., Maguire, L.A., Polasky, S., Urban, D., Boyd, J., Wainger, L. and Palmer, M., 2018. Benefit relevant indicators: Ecosystem services measures that link ecological and social outcomes. *Ecological Indicators*, 85, pp.1262-1272.

Workshop participants saw value in causal chains as a potential way to describe and link diverse categories of impacts, especially for linking social and ecological domains. Monitoring with the causal chains in mind led to two insights that may be relevant for NSB network monitoring:



- When making decisions about what to monitor, special consideration should be given to the possibility of measuring relationships. For example, instead of only measuring changes in biomass, it can be helpful to also evaluate how changes in biomass influence spillover of key species, changes in catch per unit effort (CPUE), and perceptions of fishers about livelihood impacts of MPAs.
- Causal chains can be used as a planning tool to develop hypotheses about MPAN outcomes that can be tested using monitoring data. In particular, the schematic diagrams of indicator chains can help to consider mechanisms and timelines for social-ecological change.

In addition, workshop participants pointed out that indicators along a causal chain can be informed by multiple sources of information. For example, biomass can be measured (validly) through community perceptions, CPUE, and other metrics, to provide broader insights (as elaborated on in point number 4 within this summary). Overall, using causal chains can help to establish a tighter focus of monitoring efforts on indicators that capture the more holistic and interrelated social and ecological impacts of the MPAN that can be more useful for informing decision making.

3. Standardize Monitoring Indicators and Approaches

Standardization of monitoring can be essential for enabling network-wide evaluation. Standardization can refer to both the indicators that are assessed and the methods for data collection. Several workshop participants emphasized the importance of repeatability and the value of high quality data as opposed to lower quality or opportunistic data that may not be applicable or comparable for network-scale evaluations. Additional points about standardization raised by participants included:

- In order to assess network impacts, it will be important to determine the appropriate scales for monitoring, which can vary depending on the value or process of interest, such that a multiscale approach may be needed,
- Mismatches of scale between social and ecological indicators are common and require forethought about which ones pair best with respect to spatial and time scales,
- Consistency in the seasonal timing of data collection will matter for many ecological and social indicators,
- It may be advantageous to co-locate monitoring of different indicators at the same sites to support analyses and understanding of causal relationships between indicators

subject to the same external influencing factors at each site (e.g., temperature, land-based inputs), and

- There is value in coordinated monitoring across the network (e.g., via Indigenous Guardians) to extend capacity for monitoring in remote regions and support inclusive and collaborative governance.

4. **Implement Participatory and Transparent Monitoring Processes**

Coordination and engagement among all MPA governance partners and stakeholders is essential for the development of transparent monitoring processes. While a lot of focus for monitoring programs relates to *what* to monitor (i.e., indicators and metrics), it can be equally important to consider *where* and *how* to monitor, as well as *who* does the monitoring. Interpretation of MPAN outcomes will be influenced by the sites chosen and the expected response timelines and magnitudes for each indicator given the context of each MPA site. Of particular emphasis for workshop participants, though, was that NSB monitoring should also consider the intended human 'beneficiaries' of the network (as well as other people who will be impacted) and what they would like to see monitored. First Nations as well as other user groups (e.g., recreational and commercial fishers) should be full participants in decision-making processes for prioritizing what to monitor. Further, First Nations rightsholders and other user groups can be important contributors to collaborative, coordinated monitoring approaches, particularly in the remote regions like the NSB where community-based monitoring is expected to play a large role on overall MPAN monitoring efforts.

5. **Design Monitoring and Evaluation with Equity in Mind**

Equity and justice were discussed by workshop participants along several dimensions. Workshop participants emphasized the importance of considering equity in terms of (1) deciding what indicators to monitor that reflect community concerns and interests (i.e., of all First Nations and user groups), (2) deciding how and who to monitor to understand the social effects of MPANs (positively, neutrally, or negatively), and (3) how user and community perceptions about change or effectiveness of MPAs aligns (or doesn't) with the results of social and ecological indicator monitoring. A few examples helped to illustrate discussions during the workshop. First, in terms of social impacts from the MPAN, will all communities within the NSB region be monitored? How will effects on First Nations who were not involved in the planning and endorsement process be monitored and evaluated? Second, the issue was also raised that social monitoring can be time-intensive for members of the communities of interest and can create a burden that leads to 'consultation fatigue', particularly when they are not compensated for their time. Finally, participants also discussed the importance of monitoring to assess the equitable distribution of benefits and impacts from the MPAN. This distribution of effects may be measured through changes in food security, fisheries catch per unit effort, opportunities and revenues from tourism and recreation, continuity or rebuilding of cultural practices (Indigenous and other communities), and perceptions about trust and empowerment.

6. Build on Existing Work Within the Region

Several workshop participants were highly familiar with the NSB and pointed out that there is a good amount of monitoring and research already underway within the region that should serve as a foundation for the development of a MPAN monitoring program.
For instance, the Marine Plan Partnership (MaPP) has already identified 14 key indicators of ecological, social, and economic importance in the region and have initiated monitoring of some of these indicators as part of the implementation of regional and sub-regional marine plans. Other entities including academic researchers, NGOs, and communities, are also monitoring other features in some or all of the region. A critical exercise to inform monitoring plans for the NSB network will be to map out all existing monitoring and research activities within the region that could be built upon - a task that is currently in progress and being led by members of the NSB planning team within DFO.

7. Consider Multiple Knowledge Systems to Inform Indicators

Participants highlighted the potential for, and value of, drawing on multiple sources of knowledge and information to inform monitoring and evaluation of indicators. With the Marine Plan Partnership for the North Pacific Coast (MaPP) and Guardians programs well established within the NSB region, there are considerable opportunities for and benefits from taking a two-eyed seeing approach to monitoring (e.g., Reid et al. 2021). To this end, several workshop participants emphasized the importance of selecting diverse indicators that represent different ways of knowing about change for a given value of interest (e.g., abundance and biomass, amount of community catch of key species of cultural or subsistence importance, perceptions of ability to meet subsistence needs, and shifting narratives about the quality of catch compared to historical catches as different sources of information on fish populations and the ecosystem benefits they provide). Collecting multiple types of indicators for any given value also provides the opportunity for additional insights through comparison to understand whether complementary indicators are divergent or trending in the same direction, and why this might be. For example, when both ecological and linked social indicators are doing poorly, additional management of environmental factors may be needed. On the other hand, where there are positive signals in ecological variables paired with negative signals in social variables, additional community and resource user outreach, education, and engagement may be more productive .

8. Consider Timing of Outcomes and Manage Expectations

While perceptions of MPAN outcomes are critical, several workshop participants emphasized that the public and those who live and work in the NSB may not fully appreciate timelines for ecological recovery and change. It can be important to select a mix of indicators that will detect early, medium, and long term responses. More immediate outcomes are likely to be social, and they will occur even before a MPAN is established (e.g., conflict, community cohesion). The immediate effect of establishing a MPAN will also be social because that is when access is affected for fishing and other activities.

Workshop participants also pointed out that a lack of change in certain key indicators (e.g., biomass) does not necessarily mean that the MPAN is failing to meet objectives. The lack of change may occur if a site was not heavily impacted by human activities like fishing prior to MPA establishment, or if external factors (e.g., El Niño events) are influencing those variables. With this awareness, the timelines for monitoring and evaluation can be aligned with timelines of expected benefits of MPAs. For example, one approach suggested during the workshop was to collect data regularly and for a long time at select sites, and then add 'deep dives' into data collection at longer intervals (i.e., 5, 10, 15, 20 years) based on what is known about marine ecosystem recovery timelines.

For these reasons, it can be important to communicate hypotheses about expected changes and associated timelines. Causal chains can also assist with communicating these hypotheses and why certain social and ecological changes can take longer to emerge as positive outcomes.