MaPP Kelp Monitoring Conceptual Model and Roadmap

FINAL Report

May 2023

Prepared for the Marine Plan Partnership

ESSA

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Prepared for:

The Marine Plan Partnership

Contacts:

Jen Temple

jtemple@mappocean.org

Prepared by:

ESSA Technologies Ltd.

Primary Contact:

Natascia Tamburello
Sr. Systems Ecologist
ntamburello@essa.com
604-677-9561

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ESSA Technologies Ltd.
Vancouver, BC Canada V6H 3H4
www.essa.com

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1 Introduction

The Marine Plan Partnership for the North Pacific Coast (MaPP) is a co-led process between 17 First Nations and the Government of the Province of British Columbia that developed and is implementing sub-regional plans for marine uses on B.C.'s North Pacific Coast, now and into the future. The four MaPP sub-regions are Haida Gwaii, the North Coast, the Central Coast, and North Vancouver Island. The four MaPP marine plans are being implemented at the sub-regional level, and, where appropriate through regional initiatives as identified in a Regional Action Framework (RAF).

A Memorandum of Understanding (MOU) signed between the MaPP partners in March 2015 outlines the responsibilities of a Marine Working Group (MWG). These include providing strategic direction and executive oversight to MaPP implementation activities, and developing a work plan that details outcomes, outputs, activities and completion dates. The MWG is supported by the MaPP Implementation Technical Team (MITT) that includes sub-regional co-leads and technical staff from each partner organization and other support personnel. The MITT is tasked with carrying out the work plan at the sub-regional and regional levels as appropriate and by the Secretariat tasked with administration and financial coordination.

The MaPP Marine Plans and Regional Action Framework include commitments to implement an Integrated Ecosystem-Based Management (EBM) Program (or MaPP Integrated EBM Program), including monitoring and reporting on a suite of ecological and human well-being indicators to: increase understanding of the state of the socio-ecological system on the North Pacific Coast and inform decision-making and adaptive management. Related initiatives advanced since MaPP entered into an implementation phase, including the development and implementation of a MaPP Cumulative Effects (CE) Framework, also prioritize indicator monitoring and reporting. In 2018/19, MaPP confirmed kelp, with a focus on both giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis luetkeana*), as a valued ecosystem component to pilot under the MaPP Integrated EBM Program.

Kelp species are valued as critical habitats and as harvested resources, including for coastal First Nations for food, social, and ceremonial purposes as well as commercial use. Kelp forests have experienced unexplained population declines in recent years in the Northern Shelf Bioregion (the MaPP study area). The importance of kelp to the ecosystem and to coastal communities, coupled with the lack of data on its distribution, abundance and condition, and its inherent vulnerability to ecological and industrial impacts highlight the need for greater understanding of kelp forests, what is impacting them, and what can be done to address declines. By collecting indicator data across the sub-regions using a set of established and regionally-consistent methodologies (Thompson 2021), the MaPP Partners aim to gain a better understanding of local- vs. sub-regional- vs. regional-scale drivers of change in kelp ecosystems and to use this increased understanding, (over time, to inform implementation of the MaPP Plans and support management decisions.

Kelp monitoring activities have been gradually implemented across the MaPP region over the last few years, which were primarily focused on capacity-building and refining monitoring and data management logistics. Once ongoing monitoring became established to varying degrees throughout the region, MaPP partners participated in a series of workshops between 2019 and 2022 to reflect on kelp monitoring progress to date, identify challenges and opportunities for improving monitoring practice, and where to go next.

In thinking about the future of kelp monitoring, many workshop participants expressed uncertainty about how the kelp monitoring data currently being collected could be used to inform marine management and decision-making. This perspective has been attributed in part to two factors. The first is a lack of clarity around how drivers of concern on the coast relate to monitoring metrics (in terms of mechanisms, direction, magnitude, and thresholds of effect). The second is a lack of clarity around what additional information is needed and what monitoring metrics, methods, and sampling designs should be used to answer specific questions about the effects of drivers and pressures of concern on kelp that can be used to inform management.

This work was conceived to help reduce this uncertainty by synthesizing the current state of knowledge on pathways of impacts on kelp and developing a systematic framework or 'roadmap' for approaching the design of additional monitoring activities aimed at informing management decisions.

1.1 Project Overview, Goals, and Objectives

The goal of this work is to help reduce the uncertainty described above by developing a regionally relevant indicator-to-impacts kelp conceptual model and kelp monitoring roadmap. The main outcomes of this work are:

- A **Kelp Conceptual Model** intended to more explicitly link the drivers of change (climate change, harvest, coastal development) to the pressures and pressure indicators relevant to kelp and marine plants (e.g., temperature, mechanical damage, substrate change, contaminants), and finally to different state indicators (e.g., kelp extent, biomass, health) relevant at sub-regional and regional scales within the MaPP region.
- A **Kelp Monitoring Roadmap** that leverages the information from the conceptual model to chart a path from priority drivers and stressors of concern to specific monitoring questions, indicator variables (including "non-kelp" indicators such as abalone density), generalized sampling designs, and potential analytical strategies for data collected. A 'menu' of monitoring options will then be available for sub-regions to choose from to further develop their own monitoring activities. The Roadmap will also describe how different scales of monitoring (local, sub-regional, regional) contribute to an understanding of kelp dynamics in the MaPP region.

The conceptual model and roadmap will be developed based on review of existing conceptual models and literature; MaPP reports, including sub-regional work and regional reports; discussions with selected experts; and meetings with sub-regional kelp monitoring stewardship and technical staff to identify sub-regional priorities and provide feedback. These products will help to bridge the kelp monitoring program with broader cumulative effects programs ongoing in the region and support the emerging development of detailed **Sub-Regional Kelp Monitoring Plans** based on local management priorities identified by Partners in each of the four MaPP sub-regions.

1.2 Contents of This Report

This report brings together multiple lines of evidence and guidance for informing the development of future kelp monitoring strategies both within Sub-Regions and across the MaPP region.

- The Kelp Conceptual Model presented in **Section 2** summarizes a substantial body of research on the impacts, indicators and metrics, and management interventions for different stressors on kelp while also providing information on other guiding questions for MaPP kelp monitoring.

- The overview principles for monitoring in an EBM context that are presented in **Section 3.2** provide foundational knowledge and best practice guidance for future kelp monitoring design intended to provide more concrete evidence for management decisions,
- The gap analysis conducted in **Section 3.3.1** assesses how well current MaPP kelp monitoring activities advance the Overarching Goals and Guiding Questions defined for MaPP kelp monitoring and whether current practices adhere to best practices, and
- The high-level recommendations provided in **Section 3.3.2** offer practical suggestions for ways forward to fill remaining gaps while acknowledging the limitations on additional monitoring.
- Note that the **Appendices** are not included in this publicly-accessible version of this report, although references to appendices remain in this document for information.

2 Kelp Conceptual Model

2.1 MaPP Kelp Monitoring Context

The MaPP Regional Kelp Monitoring Project is associated with a set of working goals whereby increasing knowledge related to kelp is intended to directly inform key management actions related to updating sub-regional marine plans, management of activities associated with stressors, and management of kelp harvest, while also providing benefits for capacity building at regional scales (**Figure 1**).

The first working goal, increasing knowledge related to kelp, is supported by monitoring activities informed by four guiding questions about kelp status, drivers of change and associated pressures, and broader ecosystem conditions. These questions can themselves be organized into a causal chain, whereby drivers of change lead to associated pressures on kelp, which are observed as changes to kelp spatial extent, biomass, and condition over time, and these changes may lead to cascading effects to fish or invertebrates that depend on kelp for food or habitat.

To date, regional kelp monitoring activities in the MaPP region have focused primarily on the middle portion of this causal chain – understanding kelp spatial extent, biomass, and condition. However, **for monitoring to directly inform management actions relating to key stressors of concern for kelp, it will also be necessary to monitor the stressors themselves**.

Monitoring stressors can help managers to:

(1) establish cause-effect relationships by analyzing stressor data in relation to standard monitoring data on kelp extent, density and condition, but that can more effectively support management decisions related to drivers of change, which are often human activities within management control. Such data is currently collected primarily through Tier 1 monitoring, but further information from Tier2/2+ and Tier 3 monitoring may also contribute as monitoring using these methods expands in the future.

(2) determine the effectiveness of management interventions applied to reduce the pressures.

It is important to understand that the status of kelp can be influenced by multiple stressors as well as other influencing factors associated with natural environmental variability. Because of this, it is also important to understand and monitor interactions between stressors as well as natural influencing factors to confirm that observed change to the status of kelp are really due to a pressure of concern, instead of broader environmental changes, before taking management action.

The **Kelp Conceptual Model** is intended to identify the key kelp stressors, indicators, and influencing factors, and explicitly map these to state indicators of kelp (i.e., changes in kelp extent, biomass, or condition) relevant at sub-regional and regional scales within the MaPP region.

2.2 Approach

2.2.1 Literature Review

Development of the conceptual model was based on a literature review of stressors for kelp. This literature review began with and built upon other recent kelp conceptual models and related knowledge syntheses developed for other initiatives and regions, most notably those described in Table 1.

Figure 1: Working goals of the regional kelp monitoring project as informed by guiding questions, which can themselves be organized into chain of cause-effect relationships.

Table 1: Summary of key conceptual models built upon in this report.

Prior Conceptual Model	Description
Toward a conceptual framework for managing and conserving marine habitats: A case study of kelp forests in the Salish Sea (Hollarsmith et al. 2022)	A conceptual model of kelp drivers and pressures based on evidence from studies from both across the globe as well as specifically from the Salish Sea. This study summarizes high-level evidence for linkages between specific drivers (e.g., climate change, vessel traffic, shoreline development, etc.) and pressures (e.g., temperature, nutrients, contaminants, etc.), as well as the direction, magnitude, and confidence of effects of different pressures on both floating and non-floating kelps.
Puget Sound Kelp Conservation and Recovery Plan Knowledge Review (Calloway et al. 2020)	A generic conceptual model and accompanying literature review on the effects of different pressures on a wide variety of kelp species, with a focus on literature from the Pacific Northwest.
A structured approach for kelp restoration and management decisions in California (Gleason et al. 2021)	A summary table (Appendix 2) highlighting direct and indirect impacts of stressors on kelp, with supporting references, as well as potential influence of those stressors on management decisions, particularly decisions related to kelp restoration.

These foundational materials were supplemented with review of additional literature on specific impact pathways to provide **a greater level of detail relevant for monitoring planning**, including:

- **filling information gaps** on mechanisms and effects for giant kelp and bull kelp,
- identifying key **variables** (what is directly measured in the field)**, indicators** (a metric combining one or more variables over space and/or time that provides a reliable way to measure change relevant to management)**,** and **methods** for monitoring variables and indicators,
- documenting **potential thresholds of concern** that could be used as management triggers, and
- identifying **interactions with other stressors** that should be controlled for when carrying out monitoring to establish cause-and-effect relationships (e.g., through stratified sampling).

2.2.2 Evidence Evaluation Scheme

We modelled our evaluation scheme for documenting direction of impact and level of evidence on the framework used by Hollarsmith et al. (2022) to facilitate comparisons.

Direction of Change

The evidence compiled from the literature review was used to evaluate the direction of each interaction between kelp and identified stressors. Positive, negative, and neutral effects were assessed based on specific criteria (Table 2 and **Table 3**). Consequence scores were limited to direct and near-direct consequences only. The degree of confidence in the direction of change was evaluated based on the number of and degree of consensus among the supporting studies examined. Note that the consensus scores were determined qualitatively, rather than through calculations of papers for or against, by considering the fraction of papers agreeing upon the magnitude and direction of impact of the pressure on kelp. In order to minimize biases in our scores, we reviewed as many papers as possible before assigning a low, moderate, or high level of consensus. The rationale considered in the qualitative score assignment are provided in the "consensus" sub-section of each pathway (see **Table 2**).

Applicability

Given the desire to emphasize evidence from within the NSB, we also scored the applicability of papers to this region based on whether studies took place within the NSB, within the broader region, or outside of the northeast Pacific region (**Table 3**Table).

Table 2: Direction and Consensus scoring scheme

Weight of Evidence		
Direction of Change	**Consensus**	
Negative interaction where kelp population health and abundance decline due to habitat degradation, species threats, pollution, etc.	**60-79%**	**>80%**
Neutral or inconclusive results in a majority of papers (60-79%) OR insufficient information in the literature to determine net effect.	**60-79%**	
Positive interaction where kelp population benefits through new habitat, increase in abundance/ biomass, increased diversity, etc.	**60-79%**	**>80%**
No consensus	<60%	
No literature		

Table 3: Applicability scoring scheme

Applicability of Evidence	
Applicability to the NSB	**Score**
Data sources are from the study areas, evaluating regional kelp species and interactions – data is very relevant and from within the Northern Shelf Bioregion	**High**
Data sources are from adjacent regions out of the study area evaluating regional kelp species and interactions and from within broader BC or the US West Coast	**Moderate**
Data sources are outside of the study area or for non-target species, using comparable proxies to evaluate effects and interactions among kelp species	**Low**
No literature	

2.3 Conceptual Model

The MaPP kelp conceptual model presented in **Figure 2** summarizes the outcomes of our research on both kelp stressors and possible management measures, with additional detail on key drivers, metrics, and monitoring methods for stressors and other variables of interest for MaPP kelp monitoring laid out in **Table 4** below. More detail on all stressors is available in the detailed Stressor Profiles in Error! Reference source not found.. The coloured bubbles in **Figure 2** below represent broad categories of management strategies drawn from the literature (e.g., sources in **Table 1**), including:

1. **Kelp Harvest Management**
   a. Use an ecosystem-based management approach for kelp harvest
   b. Modify harvest conditions, methods, and quantities to align with kelp ability to recover under different background stressor scenarios
   c. Test kelp in harvested regions for contaminants and avoid harvest and consumption of kelp from areas with high contaminant inputs known to be concentrated in kelp (e.g., metals)
2. **Land and Marine Use Management -** Minimize stressors associated with human activities to increase overall resilience to other stressors like temperature and predators
   a. Adjust land use practices to reduce land-based sediment, nutrient, and contaminant inputs
   b. Minimize dredging near kelp habitats to reduce sediment and contaminant resuspension

   c. Restriction of selected human activities that cause pressure on kelp in protected areas
   d. Where important kelp-associated fish and invertebrate numbers are low, support fisheries management, monitoring, or protected areas alongside kelp management and restoration strategies to relieve pressure on these species while the kelp they rely on recovers

3. **Kelp Restoration Strategies** – Plan kelp restoration activities to take advantage of the most suitable conditions, deliver more holistic benefits for ecological communities, and avoid areas high in stressors.
   a. Select restoration sites away from areas with high sediment and excessive nutrient inputs
   b. Time restoration activities with higher seasonal nutrient profiles to promote germination / growth
   c. Consider manually reducing macrophytes that are space / light competitors to enhance natural recruitment or prior to restoration outplanting
   d. Consider restoration in areas with current/historical presence of key fish/invertebrate species
   e. Active management of urchin populations - where urchin numbers are too high consider harvest or a periodic culling program
4. **Climate Change Adaptation Strategies** – Conduct kelp management and restoration activities with climate change in mind for more climate-resilient outcomes.
   a. Protection/restoration in thermal refugia
   b. Prioritizing protection of larger beds with greater internal area
   c. Selection of brood stock from heat-tolerant beds for restoration activities
   d. Reducing stressors that make kelp more susceptible to temperature effects

Notably, given the stressor focus of this work, the management measures presented here are **focused on measures to arrest or reverse kelp decline**. Alternative strategies may be more suitable for systems where kelp populations are **stable** (e.g., surveillance and protection) or **increasing** (e.g., precautionary approaches to assess the sustainability of additional harvest, selection from successful populations as broodstock for restoration programs elsewhere).

In general, our overall findings from elaboration of the conceptual model agreed with those of Hollarsmith et al. (2022) in terms of direction and confidence in stressor impacts on kelp, although we provide more in-depth descriptions of mechanisms and thresholds that are more useful for management purposes. Detailed information and thresholds were easier to find for water quality stressors (e.g., temperature, water clarity, nutrients, contaminants) for which published guidelines often exist, compared to others that are less often measured on standardized scales (e.g., tissue damage, algal competition). Thresholds were also easier to find for giant kelp, which has a more widespread global distribution and thus broader research coverage compared to bull kelp.

Wherever possible, we sought out evidence from studies conducted within the Northern Shelf Bioregion to create an NSB-specific conceptual model, however, the vast majority of published literature found was based on studies in southern British Columbia or the Western United States. This is perhaps not entirely surprising, as although kelp monitoring is occurring throughout the MaPP region, few sub-regions are carrying out extensive Tier 2+ level surveys that capture direct information on key pressures like temperature, salinity, substrate, and grazers, while other key stressors like nutrients, contaminants, and algal competition are not monitored across most of the region (with the exception of some coverage via the North Coast CE monitoring program).

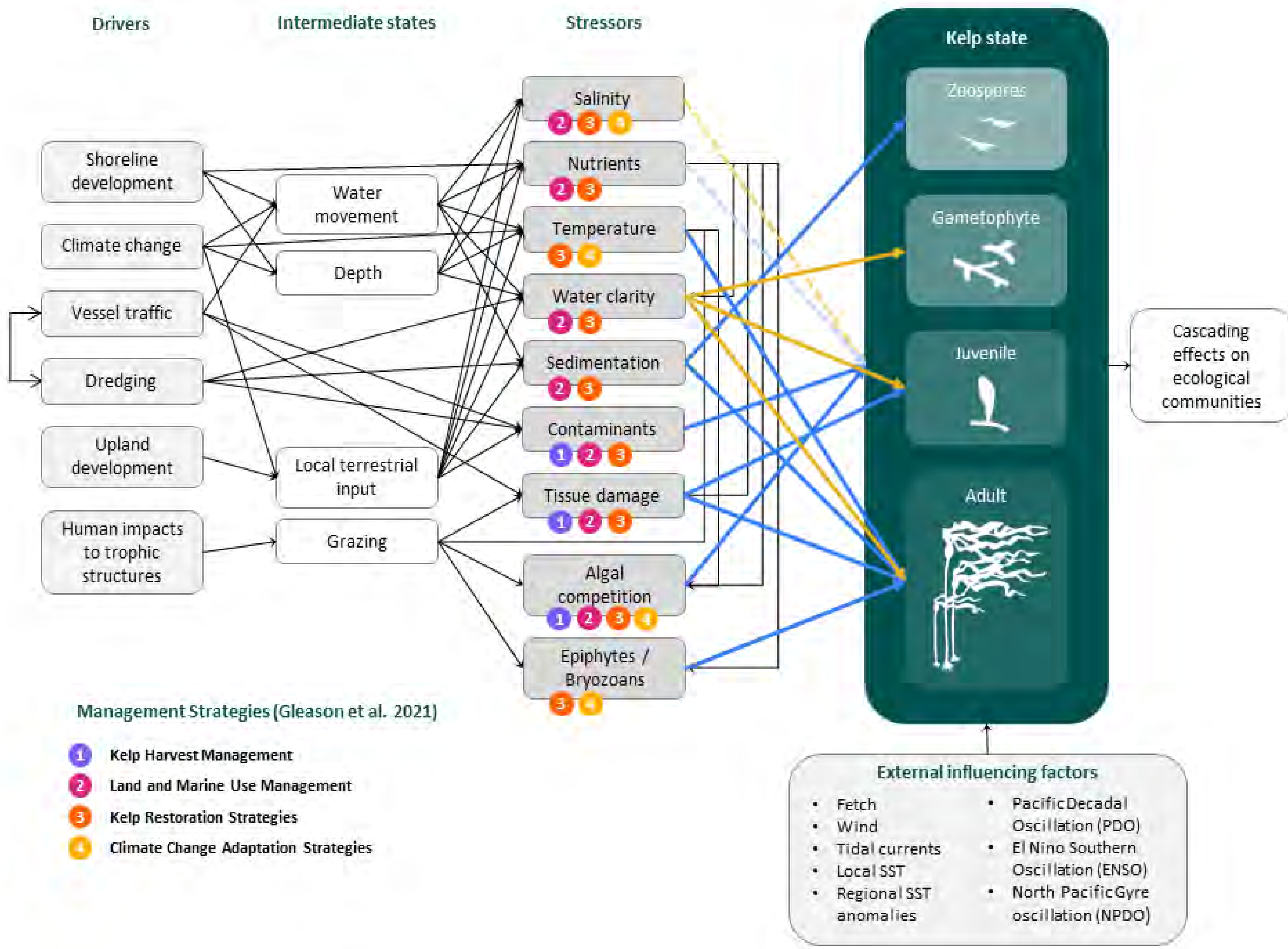

Figure 2: Conceptual model adapted from Hollarsmith et al. (2022) showing the drivers, pressures, direction of effect (positive = orange arrow, negative = blue arrow), and consensus across the literature (solid = high, dashed = moderate) of impact on the different life stages of kelp. Management Strategies to address the pressures are represented by coloured and numbered bubbles (1-4).

Table 4: Summary table of key findings from conceptual model work

Monitoring Component of Interest	Associated Drivers, Mechanisms, & Key Thresholds	Direction, Consensus, Applicability to NSB	Key Variables, Indicators, and Methods	Links to Regional Monitoring	Link to Sub-Regional Monitoring Priorities				General Management Strategies (Gleason et al. 2021)
					HG	NC	CC	NVI	
GUIDING QUESTION – DRIVERS OF CHANGE TO KELP: IF KELP IS CHANGING, WHY?									
Temperature	**Mechanisms:** High temperatures are associated primarily with climate change, including both gradual increases and marine heatwave events, but may also be caused by warm-water effluent from industrial activities. Thermal stress at a cellular level impacts kelp growth and morphology, survival, photosynthesis, reproduction, recruitment, and harvest yield. **Thresholds:** • >18 °C for giant kelp impairs growth, reproduction • >12 °C for bull kelp impairs growth, reproduction, survival • Marine heatwave conditions defined as a short-term warming (at a median of 0.15-0.20 °C/day on the Pacific West Coast) from baseline (>2 °C or SST >90th percentile of historical time series) and lasting for a prolonged period (>5 days) (Hobday et al. 2016, Spillman et al. 2021) **Related Stressors:** Elevated temperature increases kelp sensitivity to most other stressors in this study. **Influencing Factors:** Water warms more quickly in areas of poor water mixing, so high current and exposure can have moderating effects on temperature increases.	**Negative Effect** **High Consensus** **Moderate Applicability**	**Variable:** Water Temperature (°C) **Key indicators relevant to kelp:** Characterizing absolute temperatures to compare to thresholds: • Maximum absolute temperature • Number or % of days exceeding temperature thresholds, Characterizing relative temperature variability: • Mean monthly SST anomaly (difference from historical baseline) • Total number of heatwave days • Mean temperature in warmest month • Average temperature over the growing season (March – August) **Methods:** Measured by instantaneous probe (CTD) or continuous data loggers (HOBO, StarOddi, etc.) deployed at various depths to capture temperature heterogeneity	**MaPP:** Tier 2+: Oceanographic Data (water temperature at 1m, 5m, 10m below the ocean surface) **External Partners:** DFO: Collects seawater **temperature** and salinity across a network of nearshore data loggers, aiming to expand this network to add sensors for pH, nutrients, and turbidity	■	■	■		Little direct management control over climate change as a driver. Options include: • Reducing other pressures to increase overall resilience • Protection or restoration within thermal refugia • Selection of broodstock from heat-tolerant beds for restoration activities

Monitoring Component of Interest	Associated Drivers, Mechanisms, & Key Thresholds	Direction, Consensus, Applicability to NSB	Key Variables, Indicators, and Methods	Links to Regional Monitoring	Link to Sub-Regional Monitoring Priorities				General Management Strategies (Gleason et al. 2021)
					HG	NC	CC	NVI	
Tissue Damage	**Mechanisms:** Tissue damage may arise from a variety of interactions with kelp, including harvest, grazing (especially by urchins), sea otter presence / absence / occupation time (due to influence on urchins and other consumers), and contact with vessels or other human recreational activities (Krumhansl et al. 2017). **Thresholds:** No thresholds of tissue damage identified in the literature. **Influencing Factors:** Increasing temperature and poor water quality may increase susceptibility to tissue damage.	**Negative Effect** **High Consensus** **Low Applicability**	**Variables:** Density (stipes per quadrat), Appearance (rating level of tissue damage on ordinal scale), Number of fronds at the surface and Total surface length of longest frond (to compare to baseline measurements prior to damaging event such as harvest as a measure of loss and recovery) Urchin presence / density (proxy for damage) **Key indicators relevant to kelp:** Canopy growth (m·per frond per·day) Rate and degree of recovery following damage (e.g., time until reaching 100% of pre-damage density, length, etc.) Abundance (generalized linear mixed-effects model): Effects of mechanical damage to kelp tissues from grazing can be derived from the relationship of abundances of kelp and grazers using average counts per quadrat by species over time (Starko et al. 2022). **Methods:** Surface-based and underwater visual census using quadrats or transects, tagging fronds using coloured cable ties just below the surface at the point of harvest and measuring recovery as canopy growth and growth of new fronds	**MaPP:** Tier 1 (density, but no structured assessment of kelp tissue damage) Tier 2+ Kelp Bed Observations (underwater observations of urchins)	■	■	■	■	Many drivers within management control, options include: • Modifying harvest conditions, methods, quantities • Active management of urchin populations • Restriction of selected activities in protected areas • Reducing other stressors that increase kelp susceptibility to tissue damage (e.g., temperature, pollution, etc.)

Monitoring Component of Interest	Associated Drivers, Mechanisms, & Key Thresholds	Direction, Consensus, Applicability to NSB	Key Variables, Indicators, and Methods	Links to Regional Monitoring	Link to Sub-Regional Monitoring Priorities				General Management Strategies (Gleason et al. 2021)
					HG	NC	CC	NVI	
Water Clarity	**Mechanisms:** Affected by drivers including natural and anthropogenic sediment inputs from land, resuspension of particles from dredging of the seabed, and storms. Particles suspended in the water in turn reduce light penetration, which is important for photosynthesis. Heat stress can increase sensitivity to light availability. **Thresholds:** • < 200 $\mu mol/m^2/s$ irradiance impairs photosynthesis in subtidal brown algae • > 8 NTU (short-term) or > 2 NTU (long-term) increase from baseline in clear waters, > 5 NTU or >10% in naturally turbid waters **Related Stressors:** Elevated nutrient inputs can contribute to reduced water clarity by encouraging phytoplankton blooms. Heat stress can increase sensitivity to light availability.	**Positive Effect** **High Consensus** **Moderate Applicability**	**Variables:** Secchi Depth (m); Turbidity as nephelometric turbidity units (NTUs); Irradiance ($\mu mol/m^2/s$) it is possible to develop relationships to convert between these variables, though the relationship may vary by specific regions. **Key indicators relevant to kelp:** Number of days irradiance remains below critical threshold for impairment to photosynthesis (particularly over growing season) **Methods:** Secchi disk descended from surface for Secchi depth, turbidity meters for NTUs, and data loggers with light sensors for irradiance.	**MaPP:** Tier 2+: Oceanographic Data (Secchi Disk depth) **External Partners:** DFO: Collects water temperature and salinity across a network of network of nearshore data loggers, aiming to expand this network to add sensors for pH, nutrients, and **turbidity**		■			Many drivers within management control, options include: • Adjusting land use practices to reduce sediment inputs (e.g., reduce coastal development, decommission road stabilize slopes, engage in riparian and coastal restoration to help trap sediment, etc.) • Minimize dredging near critical kelp habitats. • Select restoration sites away from areas with high sediment inputs.
Salinity	**Mechanisms:** Kelp are locally-adapted to temperature and salinity levels, which vary across regions. However, rapid decreases from baseline salinity due to drivers like extreme rainfall events or increased seasonal snowmelt can lead to tissue damage, reduced recruitment and settlement, overall abundance and survival. **Thresholds:** • > 10% decrease from baseline over 30 days can be detrimental to aquatic life **Related Stressors:** Increasing temperatures can increase freshwater inputs from land due to increased melting of snowpack and glaciers.	**Positive to Neutral Effect** (depends on baseline) **Moderate Consensus** **Moderate Applicability**	**Variables:** Salinity as parts per thousand (ppt) **Key indicators relevant to kelp:** None found in literature **Methods:** Measured via refractometer or CTD Water Quality Instrument or StarOddi temperature loggers	**MaPP:** Tier 2+ Oceanographic Data (salinity measures via CTD instrument) **External Partners:** DFO: Collects water temperature and **salinity** across a network of network of nearshore data loggers, aiming to expand this network to		■			Little direct management control over driver. Options include: • Reducing other pressures to increase overall resilience • Adjustments to land use practices to slow flows, increase landscape absorbance, and reduce or draw out overall freshwater inputs • Selection of brood stock from kelp beds adapted to local salinity conditions for restoration activities

Monitoring Component of Interest	Associated Drivers, Mechanisms, & Key Thresholds	Direction, Consensus, Applicability to NSB	Key Variables, Indicators, and Methods	Links to Regional Monitoring	Link to Sub-Regional Monitoring Priorities				General Management Strategies (Gleason et al. 2021)
					HG	NC	CC	NVI	
	Influencing Factors: Proximity to significant freshwater inputs, such as estuaries or water treatment plant outfalls can contribute to low salinity levels, particularly in areas of low water mixing due to low currents and exposure.			add sensors for pH, nutrients, and turbidity					
Nutrients	**Mechanisms:** Nutrients typically enter the environment through land-based inputs of sewerage, agricultural runoff, or industrial sources. Nutrients are necessary for photosynthesis and can be limiting for growth when concentrations are low. When nutrients are excessively high, other fast-growing turf algae and macroalgae may outcompete and overgrow kelp. **Thresholds:** • <1 µmol L-1 ambient nitrate impairs growth and reproduction • 1-2 µmol L-1 ambient nitrate supports moderate growth • ≥ 10 µmol L-1 ambient nitrate concentrations support higher growth / densities, and reduced fragmentation • > 1500 (short term) or 200 (long-term) mg $NO_3^-\cdot L^{-1}$ detrimental to marine life • No high-nutrient thresholds found for overgrowth by other marine algae • C:N ratios > 15, tissue nitrogen concentrations ≤ 1% indicative of nutrient limitation	**Negative Effect** **Moderate Consensus** **Moderate Applicability**	**Variables:** Nutrient concentrations as µmol L^{-1} of individual nutrients or total dissolved inorganic nitrogen ($DIN = NO_3^- + NO_2^- + NH_4^+$) **Key indicators relevant to kelp:** Marine nutrient concentrations and duration of levels above BC Water Quality Guidelines for the protection of marine life Chlorophyll-a (chl-a) from satellite measurements of ocean colour are often used as a proxy for nutrient availability, specifically for nitrogen. Effluent water quality when there is a significant effluent source in close proximity to kelp beds. **Methods:** Nutrient concentrations measured by in-situ optical sensor or lab tests on water samples.	**MaPP:** Not currently measured by MaPP protocols. **External Partners:** <u>DFO</u>: Collects water temperature and salinity across a network of network of nearshore data loggers, aiming to expand this network to add sensors for pH, **nutrients**, and turbidity	■	■		■	Many drivers within management control, options include: • Adjusting land use practices to reduce nutrient inputs (e.g., enhance wastewater capture and treatment, reduce the use of fertilizers) • Select restoration sites away from areas with excessive nutrient inputs. • Time restoration activities with favorable seasonal nutrient profiles for germination and growth

Monitoring Component of Interest	Associated Drivers, Mechanisms, & Key Thresholds	Direction, Consensus, Applicability to NSB	Key Variables, Indicators, and Methods	Links to Regional Monitoring	Link to Sub-Regional Monitoring Priorities				General Management Strategies (Gleason et al. 2021)
					HG	NC	CC	NVI	
Epiphytes / Bryozoans	**Mechanism:** Encrustation of epiphytic organisms like bryozoans can weaken kelp tissues and make them more vulnerable to erosion, breakage, and sinking. **Thresholds:** Bryozoan loads >40% kelp raft biomass likely to cause sinking of fronds in giant kelp in Chile, no similar thresholds found for bull kelp **Related Stressors:** Increasing water temperatures can contribute to favourable growing conditions for bryozoans, and increased bryozoan cover can make kelp fronds more fragile and susceptible to tissue damage. **Influencing factors:**. Wave exposure can influence bryozoan cover by affecting settlement of bryozoan's planktonic larvae and feeding success of adult colonies. On the exposed Central Coast of BC, kelp beds with greater wave exposure had lower cover of bryozoan.	**Negative Effect** **High Consensus** **High Applicability**	**Variables:** Presence and extent of bryozoans on kelp **Key indicators relevant to kelp:** % cover of bryozoans Days from bryozoan outbreak until sinking **Methods:** Surface-based surveys of % bryozoan cover using quadrats, where % bryozoan cover is scored on a standard ordinal scale	**MaPP:** Tier 2+ Quadrat Data (% cover of bryozoan on kelp)	■	■	■	■	Little direct management control over driver. Options include: • Reducing other pressures to increase overall resilience. e.g. prioritizing harvest of kelp at cooler more wave exposed sites, consider reducing kelp harvest during warmer years • Prioritizing protection of kelp beds at cooler more wave exposed sites that may be less susceptible to future bryozoan outbreaks
Contaminants	**Mechanism:** Sources of contamination include vessel traffic, dredging, climate change, land development and discharge (e.g., mines, sewage, smelters, pulp and paper mills). Contaminants of particular concern for kelp include heavy metals (e.g., copper, cadmium, arsenic, lead, mercury), persistent organic pollutants (PAHs, PCBs, BaPs), and petroleum products. Importantly, absorption of toxins by kelp can have implications for food safety. **Thresholds:** Thresholds of concern vary widely among contaminants (see Appendix section on **Contaminants**)	**Negative Effect** **High Consensus** **High Applicability**	**Variables:** Contaminant concentration as µg chemical / kg in kelp tissue samples **Key indicators relevant to kelp:** Concentrations of contaminants exceeding safe thresholds for consumption (see Appendix for thresholds by specific contaminant) **Methods:** Measured via laboratory assays. Consider adopting the North Coast CE Program's protocols and workflows for this stressor.	***KEY GAP:*** *Not currently measured by MaPP or external partner monitoring protocols.*		■		■	Many drivers within management control, options include: • Adjusting land use and industrial practices to reduce contaminant inputs (e.g., reducing the use of chemicals, risk management to prevent spills) • Select restoration sites away from areas with high contaminant inputs. • Avoid consumption of kelp from areas with high contaminant inputs.

Monitoring Component of Interest	Associated Drivers, Mechanisms, & Key Thresholds	Direction, Consensus, Applicability to NSB	Key Variables, Indicators, and Methods	Links to Regional Monitoring	Link to Sub-Regional Monitoring Priorities				General Management Strategies (Gleason et al. 2021)
					HG	NC	CC	NVI	
Sedimentation	**Mechanism:** Land-based inputs of sediments come from agriculture, urbanization, mining, vessel traffic, dredging, and dam operations. Sedimentation can reduce kelp recruitment and survival through reducing light penetration, altering substrate suitability, or smothering. Effects closely linked to implications of sedimentation for water clarity and light penetration. **Thresholds:** • >420 mg/L sediment loading reduces spore attachment by 90%	**Negative Effect** **High Consensus** **Moderate Applicability**	**Variables:** Type / % cover of substrate **Key indicators relevant to kelp:** Particle size (µm, mm, cm, or m) and whether sediment is settled or suspended may directly impact established adult or juvenile kelps, or impact the ability of spores to anchor to substrate (kelp recruitment and survival). **Methods:** Substrate size can be categorized during kelp, fish, or invertebrate transects. Hakai protocols (2018) recommend classifying substrate type based on the following measurements: 1 = bedrock reef (>10m bedrock), 2 = large boulders (>1m), 3 = medium boulders (0.5-1m), 4 = small boulders (25-50cm), 5 = cobble (10-25cm), 6 = pebbles (2.5-10cm), 7 = gravel (0.5-2.5cm), and 8 = sand (< 0.5cm) (Hakai 2018).	**Tier 2+** Kelp Bed Observations (Primary / Secondary substrate type only)	■	■			Many drivers within management control, options include: • Adjusting land use practices to reduce sediment inputs (e.g., reduce coastal development, decommission road stabilize slopes, riparian and coastal restoration to trap sediment, etc.) • Minimize dredging near kelp. • Select restoration sites away from areas with high sediment inputs.
Algal Competition	**Mechanism:** Climate change-induced warming and acidification, land use changes increasing nutrient and pollution loads, and grazing pressure on macroalgae may favor competitor species that is expected to contribute to the shift from kelp forests to other types of macroalgae or algal turfs (Filbee-Dexter et al. 2018, Connel and Russell 2020). Prior studies have shown than these alternative algal communities become dominant in areas where kelp has never been detected or has been lost, and can be an indicator of kelp loss due to climate shifts rather than predation pressure (Gendall 2022). **Thresholds:** No thresholds identified.	**Negative Effect** **High Consensus** **Moderate Applicability**	**Variables:** Understory algal community composition **Key indicators relevant to kelp:** % cover by species Dominant species by functional group: e.g., Turf, Branched, and Kelp understory **Methods:** Consider adopting methods outlined in Gendall 2022, which measured understory as an input to ecological cluster modelling in Haida Gwaii.	***KEY GAP:*** *Not currently measured by MaPP or external partner monitoring protocols.* However, potential methods could be streamlined into existing MaPP or Hakai methods which examine the substrate (**Tier 2+, Tier 3**).					Many drivers within management control, options include: • Consider manually reducing space and light competitors to enhance natural recruitment, or as a precursor to outplanting restoration • Address other stressors contributing to competition, such as excessive nutrient inputs. • Reducing other stressors to increase overall resilience.

Monitoring Component of Interest	Associated Drivers, Mechanisms, & Key Thresholds	Direction, Consensus, Applicability to NSB	Key Variables, Indicators, and Methods	Links to Regional Monitoring	Link to Sub-Regional Monitoring Priorities				General Management Strategies (Gleason et al. 2021)
					HG	NC	CC	NVI	
GUIDING QUESTION – DRIVERS OF CHANGE TO KELP: What do we have? How's it doing?									
Spatial Extent	**Rationale:** Monitoring kelp spatial extent over time permits an examination of how drivers of change (climate change, land development, vessel presence, and human impacts to trophic structures), may affect the size of kelp forests. A reduction in the spatial extent of a kelp forest, depending on the species of kelp, may signal that environmental or anthropogenic factors are impacting the productivity of that kelp bed. **Key Protocols:** The MaPP Kelp Monitoring Protocols recommend mapping the extent or perimeter of the kelp bed using a data collection app or datasheet to map the kelp location with GPS (Tier 1-Step 2 in MaPP 2021). **NOTE:** protocols for assessing extent, biomass, and condition of non-kelp intertidal seaweed species like *Pyropia* using quadrats have also been developed as part of a research project by the Hakai Institute. See details on protocols in Error! Reference source not found., **Section** Error! Reference source not found..	**Part of core MaPP monitoring protocol**	**Boat-based measurements:** Boat surveys should be undertaken to map with GPS points (enough to connect dots and map edge) the perimeter of the kelp bed. **Drone (UAV):** Drone can be deployed to collect images of the entire kelp bed from a height of 60-120m. The height should be adjusted based on the size of the bed, obstruction heights, and weather (MaPP 2021, Tier 2+). **Aircraft:** Aerial imagery over larger scales using an aerial coastal observatory (ACO) to cover larger areas than drones. **Satellite:** Comparison of historical imagery with current imagery acquired for the purpose of determining the spatial extent of kelp and other coastal ecosystem components.	**Tier 1** **Tier 2/2+** **Aerial and satellite imagery**	■	■	■	■	Follow a precautionary approach: When kelp extent is in **decline**, reduce pressures within management control until the causes of decline can be understood and addressed with targeted management actions (e.g., see stressor rows). When kelp extent is **stable**, continue surveillance and consider protection to maintain state or promote increase. When kelp extent is **increasing**, take a precautionary approach to assess the sustainability of beginning or expanding harvest; consider selection from successful populations as broodstock for restoration programs elsewhere.
Biomass	**Rationale:** Monitoring kelp forest biomass over time can help provide insights into how drivers like climate change, alterations to trophic structures, and other environmental / anthropogenic influences may be impacting kelp health. **Key Protocols:** Hakai protocol recommends undertaking seasonal monitoring of giant and bull kelp biomass during the main growing season (April – October). This should be accomplished via in-situ	**Part of core MaPP monitoring protocol**	**Density quadrats from a boat / kayak:** Kelp density measurements depend on species. For **giant kelp**, use 1m^2 quadrats either along a transect, or at the GPS point locations established during the boat-measurements of the spatial extent. Kelp density is measured by counting kelp fronds that fall inside the quadrat (at the surface). For **bull kelp**, use the same methods but count the bulbs that fall within the quadrat and measure the stipe diameter at its	**Tier2 / Tier 3 / Hakai Protocols** **External Partners:** Density to biomass relationships are currently being developed by Hakai, but are not yet	■	■	■	■	Follow a precautionary approach: When kelp extent is in **decline**, reduce pressures within management control until the causes of decline can be understood and addressed with targeted management actions (e.g., see stressor rows). When kelp extent is **stable**, continue surveillance and consider protection to maintain state or promote increase.

Monitoring Component of Interest	Associated Drivers, Mechanisms, & Key Thresholds	Direction, Consensus, Applicability to NSB	Key Variables, Indicators, and Methods	Links to Regional Monitoring	Link to Sub-Regional Monitoring Priorities				General Management Strategies (Gleason et al. 2021)
					HG	NC	CC	NVI	
	density and morphometric measurements to estimate biomass. Biomass is reported in kg/m^2.		widest point (~10 cm below the bulb) (MaPP 2021). **Maximum growth and biomass surveys:** Biomass can be calculated from surveys documenting the number of plants and fronds, frond length, and frond and stipe weights for plants along a transect line. Growth can be calculated by punching a hole in plant blades close to the blade origin and measuring the change in distance from blade origin to the hole on subsequent visits. Protocols vary slightly by species – see Hakai protocols for full details (Hakai 2018). **Models:** Morphometric measurements, density to biomass relationships, and the overall extent of kelp beds can be used to estimate the total biomass of beds.	applicable to a regional scale.					When kelp extent is **increasing**, take a precautionary approach to assess the sustainability of beginning or expanding harvest; consider selection from successful populations as broodstock for restoration programs elsewhere.
Condition	**Rationale:** Monitoring kelp bed condition qualitatively over time, can help provide insights into how drivers like climate change, grazing or vessel presence may be impacting kelp tissues, and subsequently kelp health. Notably, there are many potential definitions of 'condition' which influence how it may be monitored. It is recommended that monitoring partners come to a consensus on the definition to be applied and choose metrics and methods to suit. **Key Protocols:** Hakai protocol recommends undertaking seasonal monitoring of giant and bull kelp biomass during the main growing season (April – October). Productivity estimates can be derived	**Part of core MaPP monitoring protocol**	**Visual rank / qualitative summary:** estimates of bryozoan cover on kelp within a 1m^2 quadrat can be characterized on a scale of 1-6 with 1 = very low (>0 – 5% coverage), and 6 = very high (>80-100% coverage) (MaPP 2021). Categories have been updated to better capture high frequency of low cover estimates from the field. **Dive surveys (growth and erosion of bull kelp):** 2 divers should descend along an array and tag 5 plants per transect line (15 plants total). Time, stipe length, and average blade length are recorded (as well as estimate of % of blades with reproductive sori). Punch a 3-5mm hole in an "outer blade" (location depends	**Some information via Tier 2/2+** **Tier 3 / Hakai Protocols**	■	■	■	■	Follow a precautionary approach: When kelp extent is in **decline**, reduce pressures within management control until the causes of decline can be understood and addressed with targeted management actions (e.g., see other rows). When kelp extent is **stable**, continue surveillance and consider protection to maintain state or promote increase. When kelp extent is **increasing**, take a precautionary approach to assess the sustainability of beginning or expanding harvest; consider selection

Monitoring Component of Interest	Associated Drivers, Mechanisms, & Key Thresholds	Direction, Consensus, Applicability to NSB	Key Variables, Indicators, and Methods	Links to Regional Monitoring	Link to Sub-Regional Monitoring Priorities				General Management Strategies (Gleason et al. 2021)
					HG	NC	CC	NVI	
	through measurements of loss rate, biomass (see above), and density over time.		on blade length), and measure punch distance. Return to tagged plants 4-5 days later and then 1 month later to re-measure punch distance from blade origin to hole (Hakai 2018) **Density and frond tagging:** Recovery rates following harvest can be determined by density measurements (using quadrats or 1m from transect) along transects before, immediately after, and weeks after harvest. Tagging harvested fronds helps to measure survival, frond loss, production, and reproductive potential of kelp plants over time (Krumhansl et al. 2017) (see Appendix A – Tissue Damage). **Tissue quality sampling:** Hakai protocols recommend taking 3 samples of first and second-growth seaweed at intervals along transect for lab analysis (Hakai 2018).						from successful populations as broodstock for restoration programs elsewhere.
GUIDING QUESTION – ECOSYSTEM EFFECTS OF CHANGES TO KELP: What else (fish, invertebrates) is affected by changes to kelp?									
Fish	**Rationale:** Monitoring fish assemblages and their relationships to kelp forests is key to ensuring proper fishery management is undertaken, and to discern if drivers of changes to kelp forests are impacting fish communities that are supported by kelp bed habitats (Bertocci et al. 2015). **Key Protocols:** Hakai protocol recommends conducting annual diver surveys of rocky reef communities (fish and invertebrate assemblages) along transects established adjacent to visible nearshore kelp beds.	**Part of extended MaPP / Hakai monitoring protocol**	**Fishbelt transect (counts, presence/absence):** Deep water transects conducted by a single diver are set at the desired range of approximately 10-13m below the surface. The transect line should be secured to a rock or kelp, and the diver records transect number, depth, start time, substrate type, diving visibility, and kelp cover (kelp forest, fragmented kelp canopy, or no kelp canopy). The diver will then swim along the transect and record each fish encountered within 2m of the transect line (species, and visual estimate of length). The transect should	**Tier 3**	■	■	■	■	• Where numbers of kelp-dependent species remain low, support kelp recovery and fisheries management that accounts for interactions among species to reduce other pressures on fish and invertebrates until kelp recovers. • Consider role of protected areas in supporting kelp recovery and protecting against fishing pressure.

Monitoring Component of Interest	Associated Drivers, Mechanisms, & Key Thresholds	Direction, Consensus, Applicability to NSB	Key Variables, Indicators, and Methods	Links to Regional Monitoring	Link to Sub-Regional Monitoring Priorities				General Management Strategies (Gleason et al. 2021)
					HG	NC	CC	NVI	
			be placed 5m away from the end of the first one. Dives should take place within the first 3 weeks of July over the course of 2 weeks (Hakai 2018)						
Invertebrates (Urchins)	**Rationale:** Monitoring the abundances of urchin species in kelp beds is important for characterizing the relationship between grazer presence / absence / abundance and drivers (like changes in trophic cascades resulting from sea temperature increases driven by climate change) that influence their presence. Alongside kelp monitoring, urchin monitoring can help decisions makers understand the factors that contribute to kelp forest decline and cascading effects throughout the rest of the marine food web. Because of the relationship between urchin and kelp abundance, increasing urchin populations may act as an early warning signal for changes in other species following kelp decline. **Key Protocols:** Hakai protocol recommends conducting annual diver surveys of rocky reef communities (fish and invertebrate assemblages) along transects established adjacent to visible nearshore kelp beds. Size surveys and benthic swaths of invertebrate densities (% cover) should be conducted along transects (2x30m) with 6 replicates, according to the California Sea Grant protocols (California Sea Grant 2021). **Thresholds:** • Urchin biomass between approximately 668 and 1200 g/m^2 (specific threshold may vary by location, where the equivalent number of urchins depends on their size) is associated with possible thresholds	**Part of core MaPP monitoring protocol**	**Underwater transects (kelp swath & urchin quadrats):** Diver surveys along a deepwater (10-13m) fishbelt transect using quadrats over rocky substrate and documenting urchin diameter (to nearest cm), kelp species, the number of kelp stipes, and size categories for bull and giant kelps. Once complete, the diver should return to the beginning to conduct kelp swaths, counting all kelp stipes >1m tall within 1m of the transect (one side of transect only). Dives should take place within the first 3 weeks of July over the course of 2 weeks (Hakai 2018). **Drop cameras (abundances):** Record underwater abundances of urchins and other invertebrates via a camera dropped from a boat. Abundances can be assigned high (>3/m^2), medium (1-2/m^2), or low (1/m^2) classifications. Wide-angle photographs should be taken that are representative of the entire kelp bed. GPS location should be recorded (MaPP 2021).	**Tier 2+**	■	■	■	■	• Where urchin numbers are becoming too high, consider encouraging harvest (where of harvestable quality) or a periodic culling program (where not good enough for harvest). • Consider kelp habitat restoration in areas with current or historical presence of key fish and invertebrate predators (sunflower sea star) species.

Monitoring Component of Interest	Associated Drivers, Mechanisms, & Key Thresholds	Direction, Consensus, Applicability to NSB	Key Variables, Indicators, and Methods	Links to Regional Monitoring	Link to Sub-Regional Monitoring Priorities				General Management Strategies (Gleason et al. 2021)
					HG	NC	CC	NVI	
	leading to urchin-dominated community states(e.g., urchin barrens). (Ling et al. 2015, Rennick et al 2022). • When the rate or urchin consumption exceeds the rate of detrital supply from kelp beds, kelp decrease with increasing urchins (Rennick et al. 2022).								
Invertebrates (Abalone)	**Rationale:** Monitoring abalone abundances in kelp beds, alongside kelp monitoring, will help identify the relationships between drivers of change to the marine environment, the subsequent effects on kelp forest, and how changing availability of kelp influences abalone abundance and productivity. **Key Protocols:** Hakai protocol recommends conducting annual diver surveys of rocky reef communities (fish and invertebrate assemblages) along transects established adjacent to visible nearshore kelp beds.	**Part of extended MaPP / Hakai monitoring protocol**	**Underwater transects:** 2 divers descend to the fishbelt transect line established previously (see above “fish” row). One diver swims on either side of the line, counting and measuring all invertebrates within 1m of their respective side. Measurements of the longest length of the invertebrates (to the nearest cm), but do not measure species in which the adult size is <5cm across. The divers should complete 3 transects. Dives should take place within the first 3 weeks of July over the course of 2 weeks (Hakai 2018). **Breen survey (quadrats):** This survey method (developed in the 1970’s) uses 16 1m^2 quadrats to collect information on abalone density, and abalone habitat quality. Surveys were undertaken every 4-5 years (DFO 2016). **Plots:** A plot area size of 40m (along the coast) by 10m (chart datum depth) is established, and 2 reference lines (at 2.5 and 7.5m) run along the 40m length. From these reference lines, several transects (made of quadrats) are placed (perpendicular to reference lines), along which abalone abundances are collected (as well as kelp % cover) (DFO 2016).	Part of core MaPP monitoring protocol through **Tier 3 / Hakai** ecological community surveys Also monitored as a species at risk by some MaPP Partners and DFO	■	■	■	■	• Where numbers remain low and species continue to be listed as threatened, restrict harvest and closely monitor other dive fisheries for poaching to reduce additional pressures until kelp and the broader ecosystem recover. • Use an ecosystem-based management approach to management, including considering links between consumers (e.g. abalone), grazers, and predators, when managing kelp harvest. • Consider kelp habitat restoration in areas with current or historical abalone presence.

3 Kelp Monitoring Roadmap

3.1 Overview

The **Kelp Monitoring Roadmap** leverages the information from the conceptual model as well as current best practices for monitoring in an EBM context to chart a path from the guiding questions of the MaPP kelp monitoring program, particularly related to drivers of change to kelp, to specific monitoring questions, metrics and methods, and? advice on sampling designs for the types of data collected at both sub-reginal and regional scales.

The approach to roadmap development emphasizes building on existing monitoring activities and datasets, starting with (1) understanding what questions can be answered with the data already being collected, as documented in the MaPP Metadata catalogue, and then (2) asking where gaps remain that need to be filled by additional monitoring. The roadmap has been informed by the outcomes of prior kelp monitoring workshops (Tamburello 2021, 2022), scoping discussions with MaPP Partners from each MaPP Sub-Region, and follow-up correspondence with the MaPP Regional Data Analyst as well as representatives within the Sub-Regions to collate, map, and evaluate current MaPP monitoring activities and related monitoring programs and datasets on possible stressors and influencing factors.

The roadmap is laid out as follows, beginning with general principles and moving towards more specific guidance relevant to the MaPP region:

- Best practices for monitoring design within an EBM context,
  to lay a foundation for understanding the recommendations that follow
- General gap assessment
- Recommendations for MaPP kelp monitoring

More detailed sub-regional monitoring roadmaps and a regional monitoring roadmap are also included in Appendices available only to MaPP Partners.

3.2 Kelp Monitoring for Ecosystem-Based Management Decisions

3.2.1 Monitoring Best Practices for an EBM Context

The MaPP marine planning work was founded on an ecosystem-based management (EBM) framework that focuses on ecological integrity, human well-being, and governance. Within this framework, kelp was selected as the inaugural EBM indicator to pilot EBM monitoring that could inform management across the region, with the intention of scaling up monitoring for kelp and other indicators in the future.

Unlike general ecosystem surveillance monitoring programs focused primarily on tracking status and trends through time, monitoring within an EBM framework is centered on the following key principles (Dengbol 2005, Kupschus et al 2016):

(1) **EBM monitoring indicators should be viewed as the essential link between ecosystem processes and management actions;**

(2) **ecosystem responses to pressures must be understood to be causal** to be able to manage human activities related to them; and

(3) understanding ecosystem responses to human pressures within management control is **only possible if they can be disentangled from ecosystem responses among indicators and the other complex and interrelated environmental processes** that influence them.

In other words, for monitoring to meet the practical needs of ecosystem-based management, it is no longer adequate to report on the status of a few ecosystem components or indicators in isolation. Instead, it must *causally* relate the effects of human-related pressures and environmental variability on the ecosystem and the services it provides to communities, while accounting for the complexities in those relationships in terms of how ecosystem components interact with each other, with their environment, and with key pressures. Without establishing a cause-effect relationship between a pressure and kelp, or any other ecosystem component, there is no guarantee that effort spent on management will have any effects, and it could contribute to wasting resources that would be better spent elsewhere.

Importantly, establishing a causal relationship between a pressure and kelp requires a much higher standard of sample design, sample size, and analysis than simple surveillance monitoring and reliance on correlations between the ecosystem state and pressure variables. This higher standard is required mainly to help rule out the influence of the many other environmental influencing factors that could be causing an observed change in the state of kelp instead of the pressure of interest (Kupschus et al 2016).

To confidently identify the drivers of observed changes in an ecosystem component like kelp, a monitoring program must be designed as a so-called 'integrated ecosystem monitoring' survey or program to meet two key conditions (Kupschus et al 2016):

(1) **Different ecosystem components need to be sampled on comparable spatial and temporal scales** to ensure they are being influenced by the same processes and that the datasets are sufficiently compatible that they can be combined for analyses. This includes design considerations such as:

- Collecting environmental variables at every site where ecological components and pressures are being monitored,
- Co-location of monitoring for different types of indicators at the same sites,
- Meaningful integration of local, sub-regional, and regional scale processes, and
- Meaningful integration of field and remotely sensed data.

(2) **The full range and combinations of different states that exist in the ecosystem need to be monitored in a structured way** so that the relationship between states can be determined over the full range of conditions. This includes design considerations such as:

- Understanding the most critical 'influencing factors' or 'confounding factors', those environmental variables that have a strong influence on your ecosystem component of interest and could result in falsely concluding a pressure is having an effect if they are not also measured and accounted for (i.e., more likely to produce false-positive results),

- Understanding the measured or actual distribution of pressures of interest across the study region in comparison to the distribution of kelp or other ecosystem components,
- Developing a strategic sampling design that captures all combinations of the pressure and influencing factors to help tease apart the potential causal effects of the pressure (see next section for more details on sampling designs),
- Where it is not possible to monitor all combinations in the field, using the field data that is available to inform ecosystem modelling of ecosystem and component state, where reliable models are available, can help to reduce monitoring requirements.

Meeting these requirements can be challenging for field monitoring programs, particularly given the operational constraints that many face. **Key challenges** of integrated ecosystem monitoring include:

- The need to monitor more sites to meet the requirement for monitoring designs that cover all combinations of pressures and influencing factors of interest. In general, the *minimum* number of sites for covering all combinations N variables with L states per variable is N^L. For example, monitoring an ecosystem component for one pressure in the context of two other environmental influencing factors could require monitoring at up to 9 sites if states for each indicator are just presence and absence (3 variables, 2 states per variable = 3^2 = 9) and up to 27 sites if the levels may have high, medium or low levels (3 variables, 3 states per variable = 3^3 = 27),
- Operational inflexibility that constrains how and when data can be collected at monitoring sites and makes it more challenging to adapt programs to deliver data relevant to decision-making,
- The need to prioritize among indicator requirements to assess what is necessary as opposed to ideal in order meet these conditions for a smaller number of indicators,
- The need to design surveys that maximize the integration of all other available data sources, given that any given monitoring program itself will not be able to integrate all ecosystem components of interest, and
- The need for better communication, coordination, and flexibility across entities involved in monitoring to improve alignment and integration between monitoring efforts to produce more integrated ecosystem monitoring data to maximize the broad usefulness of data-collection activities, with the trade-off of reduced autonomy for individual monitoring programs.

Despite these challenges, the general view is that the potential benefits of increasingly integrated monitoring outweigh the potential risks of continuing status quo monitoring when it is not serving the needs of decision-makers.

Importantly, robust sampling designs will be critical for both understanding the causal impacts of environmental pressures to inform management, and for understanding the causal effect of restoration and aquaculture activities to understand which methods actually work or don't work to inform more effective approaches in the future.

3.2.2 Monitoring Questions and Designs to Support Management Decisions

Establishing causal relationships between ecosystem components and pressures requires more attention to both how monitoring questions are defined and how the monitoring studies meant to answer them are designed. Here, we define the different types of questions, and show how they are linked to different requirements for levels of evidence and associated monitoring designs to help managers choose the right monitoring designs for the level of questions they want to reliably answer.

A - Specifying a Decision-Relevant Monitoring Question

Monitoring questions help to define the focus and goal of any monitoring activity or program and can help to define how managers understand progress towards environmental management goals and objectives.

Monitoring questions can be grouped intro three broad categories (Hayes et al. 2019):

- **Knowledge Development Questions:** These aim to develop a better understanding of ecological values and pressures in an area of interest and are usually focused on baseline monitoring and summary statistics on samples to estimate the broader presence, abundance, or distribution of the value or pressure of interest in the broader area or 'population' from which samples are drawn.

  In the MaPP Kelp Monitoring Project, **the guiding question "What do we have?"** is clearly a knowledge development question.

  EXAMPLE QUESTION: "What is the overall distribution and abundance of kelp across the NSB?"

- **Data Mining Questions:** These aim to identify trends or relationships within the sample data of interest (e.g., through exploratory data analysis via plotting) or the broader population from which samples are drawn (e.g., through inferential analysis such as correlation). However, as the saying goes, 'correlation does not equal causation', and so the reasons for the correlation and the existence of other related correlations that might be influencing the first are unknown.

  In the MaPP Kelp Monitoring Project, **the guiding question "How's it doing?"** is clearly a data mining question.

  EXAMPLE QUESTION: "Is there a relationship between sea surface temperature and the spatial extent of kelp?"

- **Causal Questions:** These aim to understand what is actually causing the relationships or trends observed in the monitoring sample or inferred in the population. This type of question is

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WHAT IS A "TREATMENT"? The treatments in a marine EBM context could be an environmental event like a heat wave or fuel spill, the implementation of a management intervention like kelp restoration, the designation of a new MPA, or the implementation of new education or compliance program.

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the most relevant for management in that it asks about how **'treatments'** might influence the direction and magnitude of change of a valued ecosystem component.

Importantly, this type of question can also be used to ask about the performance of models, in terms of asking how accurately a model predicts key ecological relationships.

Guidance for **how to clearly specify a causal monitoring question** to best inform monitoring design suggests that these questions include four key "PICO" elements referring to:

- **P:** a target **population**
- **I:** an **intervention**, in many cases a management action
- **C:** a **comparator** population where no intervention occurred
- **O:** a measurable **outcome**

In the MaPP Kelp Monitoring Project, both of **the guiding questions "If changing, why?"** and **"What else is affected?"** are clearly causal questions. The first is asking about how changes in exposure to different ecosystem pressures might *cause* changes in the state of kelp and the second is asking a question about how changes in the state of kelp might in turn *cause* changes in other ecosystem components.

<u>EXAMPLE QUESTION (if changing why?)</u>: "Does the removal of sea urchins (I) increase the extent (O) of kelp beds (P) compared to areas where urchins are not removed (C)?"

<u>EXAMPLE QUESTION (what else is affected</u>?): "Does reduced kelp density (I) increase the proportion of cryptic vs. exposed (O) abalone (P) compared to areas where kelp density is not reduced (C)?"

B - Choosing Sampling Designs for Establishing Causal Relationships

Importantly, not all monitoring designs are able to successfully answer all types of questions, and moving from knowledge development to causal questions required an increasing level of rigor in sampling design to reliably answer the question.

A recent review of key types of monitoring designs for a marine context provides an extremely helpful guide for understanding the different strengths of evidence associated with different types of monitoring designs (Hayes et al. 2019), as organized into **an evidence hierarchy**, and how they align with the 3 types of monitoring questions. These designs are applicable to both long-term monitoring as well as shorter-term experimental studies. Within this framework, it is generally understood that management decisions often require the highest strength of evidence possible to justify the possible trade-offs of the management action in terms of lost economic or other opportunities. The types of monitoring designs are described verbally below and graphically in **Table 5**, **Figure** 3 and **Figure** 5, and more information on controlling for confounding variables mentioned in this section are provided in the next section.

Many of these designs can apply to both comparisons between samples or sites within a 'snapshot' in time, or comparisons between samples or sites over a longer time series. Where evaluation of the effects or impacts of an intervention rely on comparison of time series data, some additional considerations are warranted to minimize the potential for misleading results, summarized in **Figure 4**. These include considerations about what metric of change you are most interested in– comparing the **average** value of an indicator across the time series or the **trend** in that indicator across the time series, whether you are more interested in the immediate response of the indicator right at or after the implementation of the intervention, and how you will control for effects such as zero values or time lags in the analysis to reduce the potential for misleading results (Wauhchope et al. 2021).

Table 5: Summary of different types of monitoring and study designs in the context of an evidence hierarchy, ranging from the strongest to the weakest levels of evidence (adapted from Hayes et al. 2019). These types and descriptions align with the visual representations of study designs in Figure 3, Figure 4, and Figure 5.

Strength of Evidence	Type of Design	Definition
1 (Strongest)	**Randomized Controlled Trials and Time Series**	Includes several types of study designs such as before and after / before-after-control-impact (BACI) studies, time series, and cross-over studies, but with the requirements that **sample units are "randomized"** (or randomly allocated to either the control or treatment groups) and **spatially balanced** (evenly spread over the distribution of the resource of interest) to help increase the likelihood of a **representative** sample (one that is representative of the whole population of interest, not just the parts of the population sampled) and minimize the effects of **confounding variables** (more on this in the next section). When properly planned and implemented, these randomized controlled trials (RCTs) are the most powerful forms of scientific evidence for an individual study. However, randomized studies are not always possible in an environmental context because the distribution of many ecosystem components and pressures is non-random (e.g., the location of fishing, sewerage outfalls, MPAs, etc.), except in the context of a manipulative experiment (e.g., experimental fishing or urchin removal at specific sites, etc.) which can be logistically challenging. This design is used in only about 12% of field studies examined in the literature (Hayes et al. 2019). Notable, **investigations into the effectiveness of BACI designs for detecting impacts in kelp forest communities** in California highlighted a few important limitations of this method for ecosystems like kelp forests and highly variable spatial and temporal dynamics (Rassweiler et al. 2021): • This design is most effective at detecting impacts for species with stable, widely distributed populations. • This design is not good at detecting small, highly localized impacts, and performs best at detecting severe impacts at moderate to regional scales.

Strength of Evidence	Type of Design	Definition
		• Analyzing groups of species together improves the ability to detect impacts to the overall community compared to looking at species individually. • Explicitly accounting for autocorrelation within the data when conducting statistical analysis can help to reduce false positive detection of effects from a treatment or impact. An example of serial autocorrelation is when the current value of environmental variables strongly influences future values, for example, such as in the El Niño and La Niña oceanic climate oscillation cycles).
2	**Non-Randomized Controlled Trials and Studies**	Includes the same types of study designs as above: before and after / before-after-control-impact (BACI) studies, time series, and cross-over studies, except that **sample units are not randomized but deliberately selected into** either the control or treatment group. To maintain a high level of evidence without randomization, these studies need to ensure they are still drawing a **representative** sample, meaning that the sampling units selected represents the variability within the target population and especially of the many influencing and confounding variables that affect that population. Spatially balanced samples can help to improve representativeness even without randomization.
3	**Cohort, Case-Control, and Cross-Sectional Studies**	Observational studies that are controlled, but with no deliberate role in how the treatment is assigned to different sampling units. Three types include: • **Cross-sectional study:** Takes a sample from one point in time across a well-defined population and infers a treatment effect by comparing outcomes between sites with and without the treatment Example: Taking a sample from all known kelp beds in the NSB and then looking for differences in outcomes among sites with land-based sediment inputs versus those without. • **Cohort study:** Selects two or more study groups based on exposure to a treatment and then compares outcomes between those two groups. Example: identifying random sample of kelp beds and grouping them based on level of protection in that area, and the comparing kelp state indicators across groups.

Strength of Evidence	Type of Design	Definition
		• **Case-control study:** Allocates sample units to one of two or more groups based on their outcomes, and then looks at the level of treatment each outcome group received. Example: A manager might choose two groups of kelp beds, one group in poor condition and one in good condition, and then assess the levels of different pressures each group has been exposed to, to look for commonalities. The quality of evidence of these studies depends on how well the allocation of sampling units within each group controls for influencing or confounding and non-confounding variables, for example, using techniques like randomization (see next section for more information).
4	**Uncontrolled Time Series and Studies**	Uncontrolled studies or time series observe some metric *only* from within an area where a treatment has occurred (e.g., monitoring only in the immediate area of kelp harvest as opposed to comparing harvested and unharvested beds). This is considered a weak form of evidence because, without comparing to a control area, it is impossible to determine if the treatment caused the change observed.
5 (Weakest)	**Expert Opinion**	Includes activities like expert-based mapping, ranking, definition of stressor response curves based only on knowledge and experience. Sometimes the only source of information where data are limited. Weak strength of evidence when used alone due the a high probability of bias and systemic error, but more powerful when it informs purposive sampling design for other types of designs. Biases can be reduced by following best practices during elicitation (e.g., O'Hagan et al 2006).

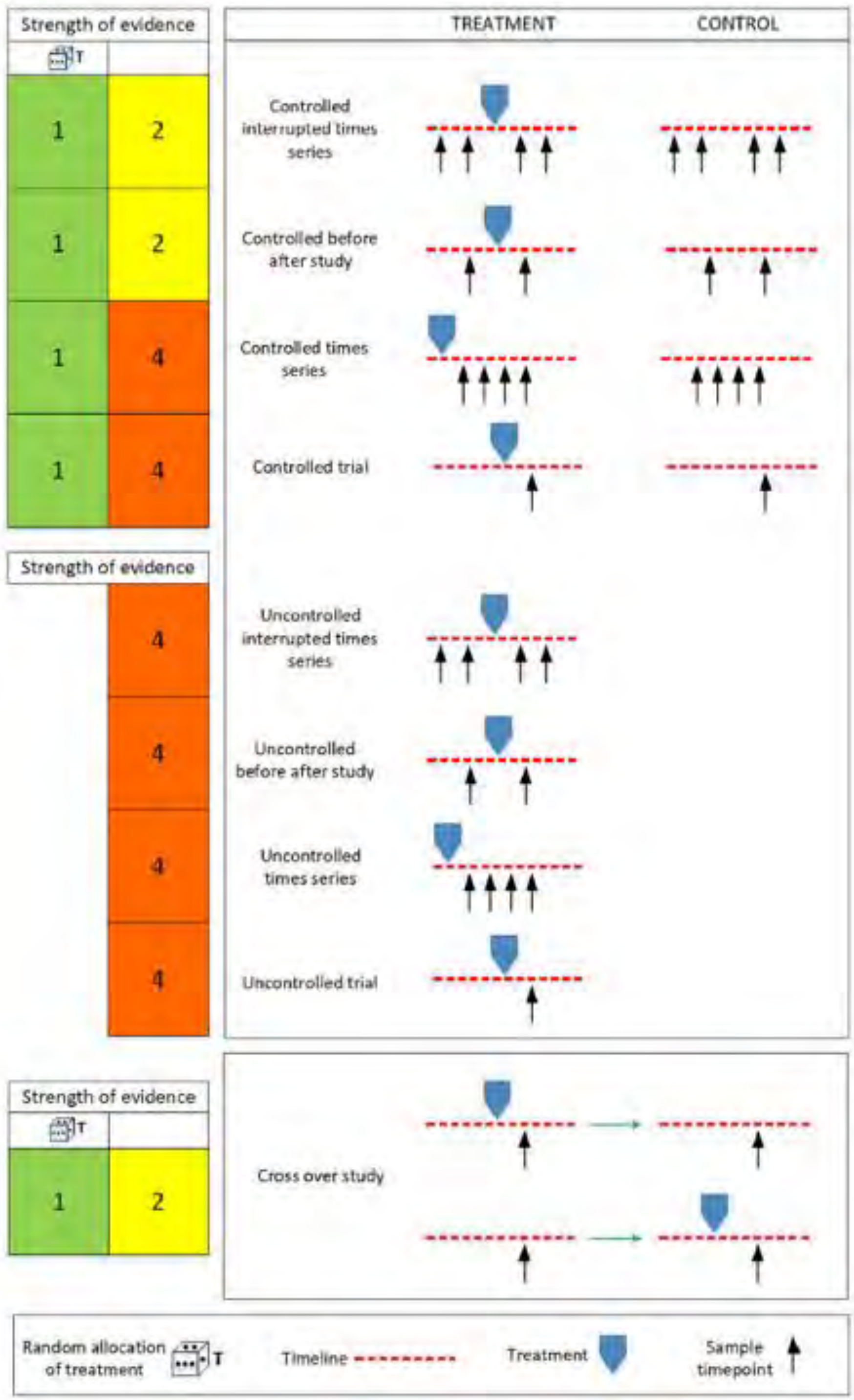
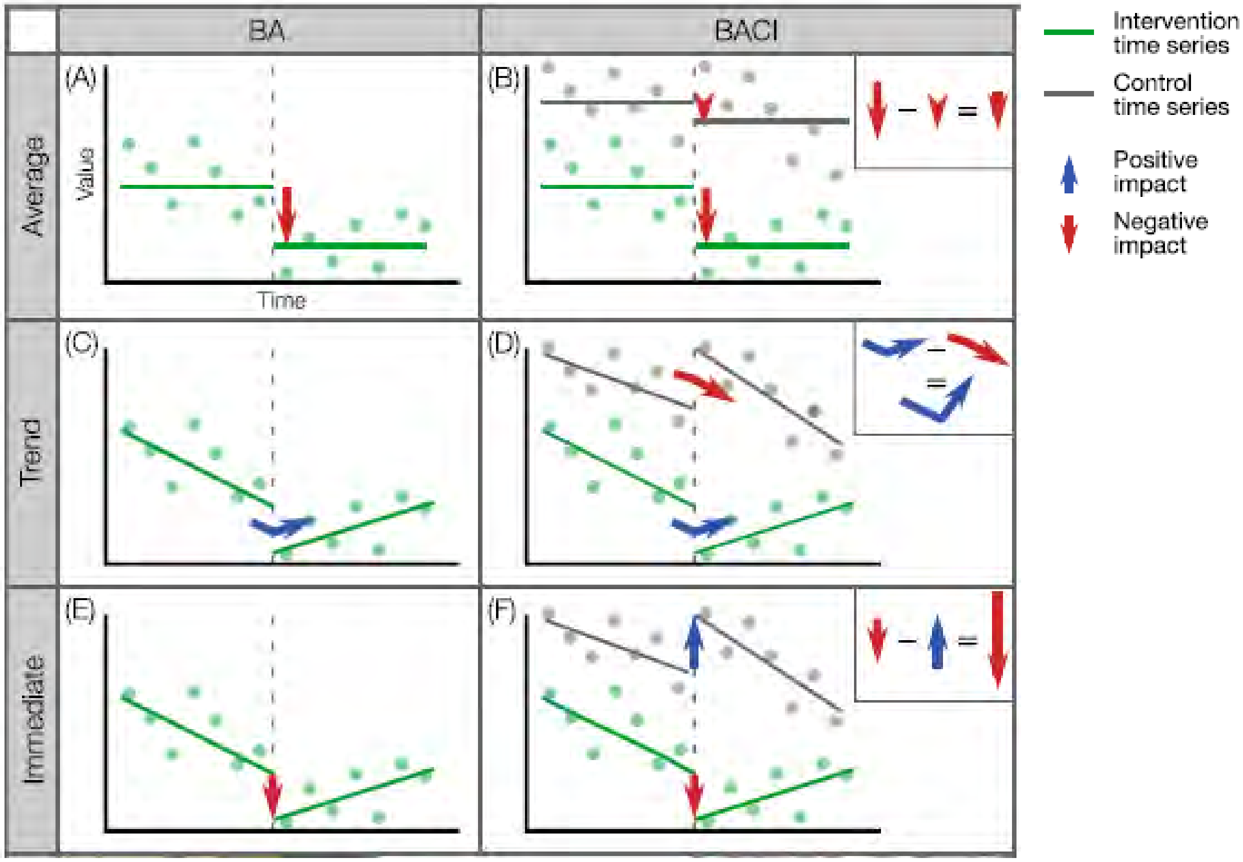


Figure 3: Schematic illustration of the evidence hierarchy for randomized controlled trials, non-randomized controlled trials and cross over studies. The die represents randomization at the level of treatment. The strength of evidence is always stronger with treatment randomization (first column on the left) than without it (second column on the left). The colors in the columns to the left reflect the strength of evidence and are numerically ranked from highest (1) to lowest (5). The "treatment" in this context could be an environmental event like a heat wave or fuel spill, the implementation of a management intervention like kelp restoration, the designation of a new MPA, or the

implementation of new education or compliance program (Table 1). Reproduced from Hayes et al. 2019.



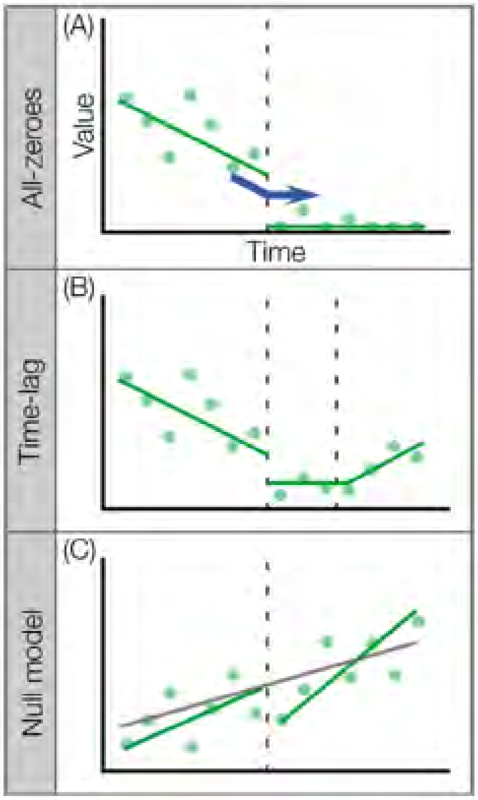


Figure 4: TOP PANEL - Average, Trend, and Immediate Change approaches when assessing the impact of an intervention (broken vertical line) using Before-After (BA) (corresponds to an *uncontrolled* before after study in the previous figure) or Before-After-Control-Impact (BACI) (corresponds to a *controlled* before after study in the previous figure) monitoring or study designs. Blue arrows indicate positive change and red indicate negative change. Impact can be defined by change in average (A, B), change in trend (C, D) and/or an immediate change (E, F). BACI comparisons show the BACI Contrast, (i.e., the difference in the change in before to after, between control (grey) and intervention (green) time series. In this example, average and immediate change indicate a negative impact, but trend change indicates a positive impact.
BOTTOM PANEL – Special considerations when analyzing impacts using time series: (A) are there cases of all-zeroes? (B) Is there likely to be a lag time between the intervention (left broken line) and when the population responds (right broken line)? (C) Does the impact evaluation model perform better than a null model which does not include the intervention (grey line)? Accounting for these in analysis is important to reduce the possibility of misleading conclusions. Reproduced from Wauchope et al. 2021.

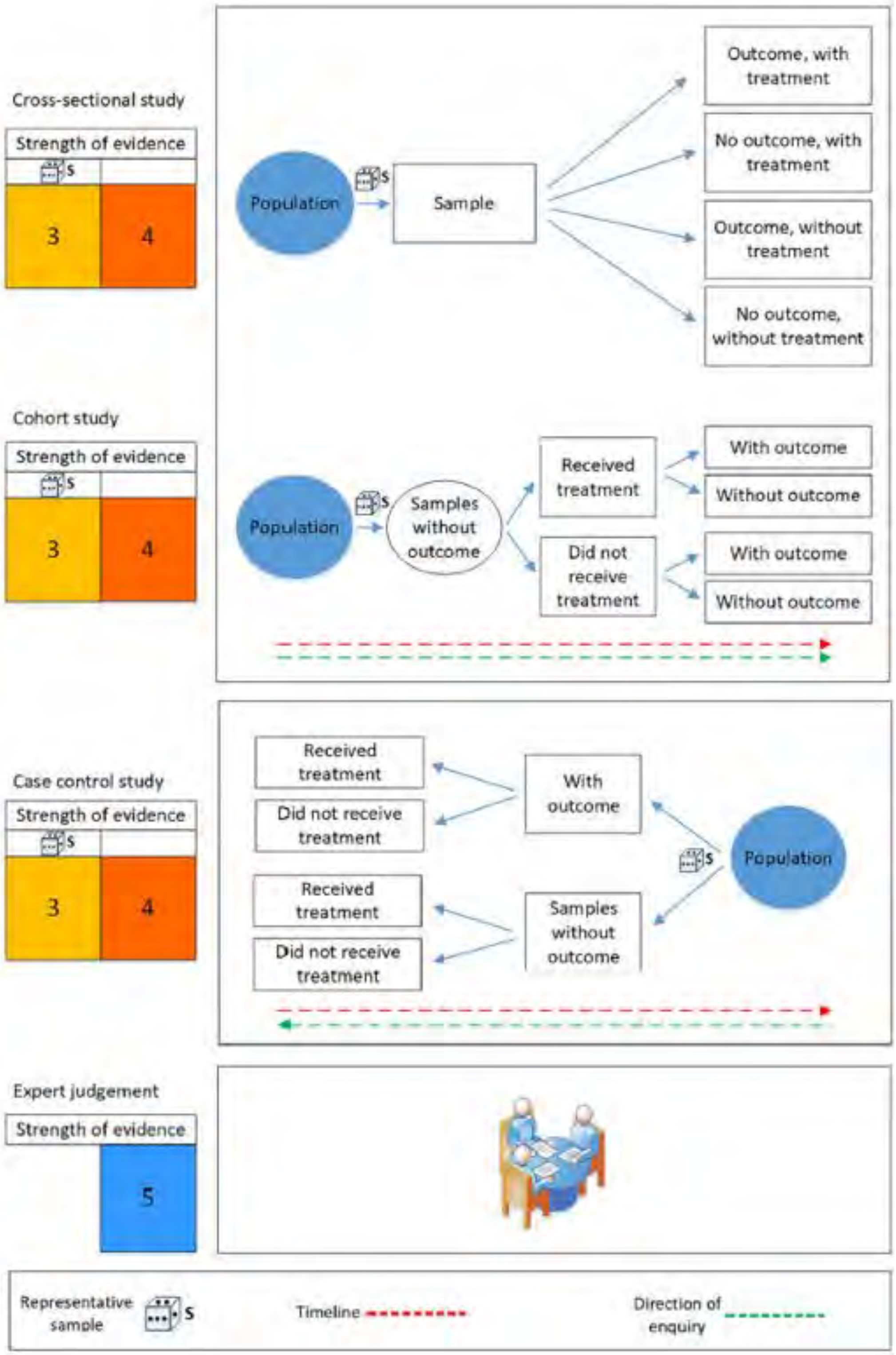


Figure 5: Schematic illustration of the evidence hierarchy for observational studies and expert judgment. The die represents selection of a representative sample by, for example, a randomized sampling scheme. The strength of evidence is diminished if the sample is not representative of the target population (second column on the left). The colors in the columns to the left reflect the

strength of evidence and are numerically ranked from highest (1) to lowest (5). Reproduced from Hayes et al. 2019.

C - Controlling for Influencing or Confounding Variables

When managers want to know if a 'treatment' like an environmental condition or a management intervention are causing a change in a value of concern like kelp. For causal monitoring or study designs, it is critical to ensure that the sample is both representative of the target population, and also controls for any influencing or confounding variables other than the treatment of interest that might be contributing to the observed state of a value of concern.

How to IDENTIFY Influencing or Confounding Variables to Control?

Identifying the influencing or confounding variables to control for is based on our understanding of the study system, and often begins with literature review and the development of **conceptual models** (Kupschus et al. 2016). The literature review and resulting kelp conceptual model developed and presented in **Section 2** of this report is a useful starting point for identifying these influencing or confounding variables, along with variables of interest that could be considered "treatments" whose effects on kelp we are interested in understanding.

How to CONTROL for these Influencing or Controlling Variables?

Controlling for confounding variables is usually done in one of two ways described below, or through a combination of these approaches (Hayes et al. 2019).

Through Survey Design

- **Manual matching or pairing**: by selecting treatment and control sites in one of two ways:
    - **Matching for similar environmental background characteristics** (e.g., monitoring the effects of harvest on kelp at treatment and control sites only in areas with the same), but this strategy would not be able to detect the unknown effects of other levels of the matched variable or other variables that are not matched. In other words, the other variables that might influence the outcome do not vary in the sample data, so their effect can not be ruled out.
    - **Matching across different levels of influencing background attributes** (e.g., monitoring the effects of harvest on kelp in a set of treatment and control areas with high, medium or low sea surface temperatures). This latter strategy better addresses influencing or confounding variables, but can be challenging when the number of influencing or confounding variables is large (as noted for covering all combinations of covariates in Section 3.2.1).
- **Randomization and higher sample sizes**: by selecting sample sites from within control and treatment sites randomly from across the population of the valued component of interest *makes it more likely* that the overall sample, across all sites, will be **representative** of the full population and will **reflect the different combinations of influencing or confounding factors** other than the treatment that could affect the outcomes.

These benefits or randomization accrue *on average*, meaning that these benefits are more likely to emerge with larger sample sizes.

- **Spatially-balanced sampling**: by selecting sample sites that are evenly spread over the distribution of the resource of interest, with not many clumps or empty areas in the distribution of sample sites, which can help to increase the likelihood that areas which may contribute more uncertainty to population estimates will be samples.

  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 – for example, selecting random sites only within areas where kelp is known to exist, areas that are more accessible by communities, or other selection criteria of interest.

Through Analysis

- In other cases, a statistical model can be used to **account for influencing factors as random effects** in generalized linear modelling of relationships (e.g., Rassweiler et a. 2021) or to **model the 'counter-factual" outcome**, that is the outcome that might have occurred at a treatment site in the absence of a treatment, based on our understanding of the system and data from similar control sites (Hayes et al. 2019). This approach can help to answer questions such as "What would have happened to kelp biomass at this specific harvested site if harvesting had not been allowed, based on what we learned from sites where harvesting was never allowed?" However, this method may require more assumptions than accounting for confounding factors through careful study design.

How to COORDINATE Sampling Designs Across Entities and Programs?

Monitoring at Sub-Regional and Regional scales often involves a diversity of activities that can't be accomplished by any one organization, and requires coordination between organizations. Coordination can be facilitated directly through sampling design through the use of a **master sample**.

A master sample is a set of standard sampling points spread across the entire region of interest for an overarching monitoring purpose, along with an "oversample" of extra points that can be used to add new locations to the program as new needs arise (e.g., expansion of regional sampling activities, more intensive sampling in specific areas to test hypothesis or after unexpected events like heat waves or pollution spills) (Stein and Lacket 2012, van Dam-Bates 2017). The master sample can then be sub-sampled to meet the needs of different monitoring activities and programs.

When multiple organizations agree to using a master sample, individual monitoring programs select subsets of sampling sites from the master sample for their specific monitoring questions. This means that there is a greater likelihood of multiple types of monitoring occurring at the same sites and, when standard protocols are used, can make it much easier to combine datasets and carry out analyses at broader spatial scales.

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 at any time.

Tools for Sampling Design in Marine Environments

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 in the data (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).

3.2.3 Relevance of Long-Term Monitoring for Short-Term Management Experiments

Although the MaPP kelp monitoring project is focused on long-term monitoring at specific sites to detect change in key indicators over time, it can provide many spin-off benefits for short-term monitoring in the context of short-term studies such as **management experiments**.

When new management interventions are being considered in any system or specific location, they are usually implemented first in the context of one or more pilot studies which can be considered a management experiment. These studies can help to establish how well the management intervention performs in a specific environmental and site context (i.e., in the presence of specific environmental and human stressors), and usually compares variations on the management intervention to see which one works best for future applications.

The MaPP kelp monitoring project can help to support these studies in two ways:

1. **Through informing more robust study designs** based on the outcomes of this report:
    - In the Conceptual Model: Potential pressures and environmental influencing factors for kelp that would need to be controlled for in management experiments.
    - In the Roadmap: Key considerations in study design that are needed to establish causal relationships between management interventions and outcomes, while controlling for influencing factors.
2. **Through the establishment of long-term monitoring of kelp sites which can potentially act as control sites** when carefully paired with management experiment sites and when the same monitoring protocols are used. These long-term monitoring sites can help managers to understand whether management interventions are succeeding or failing because of prevailing environmental conditions (e.g., whether both experimental and control sites are both responding to the benefits of a very cool-water year or the impacts of a very warm water year) as opposed to the management intervention itself. Using existing control sites also creates economies of scale, given that they are already being monitored through an existing program.

We illustrate these concepts below in a series of vignettes on key management experiments relevant to kelp below.

Case Study: Kelp Restoration and Aquaculture

There is growing interest in **kelp restoration** across the Pacific Coast and beyond to attempt to offset the significant decline in kelp populations over recent decades as a result of human activities, ecosystem shifts, and climate change (Eger et al. 2022ab). Experiences through these efforts have yielded important insights, lessons learned, and guidance for planning, implementing, and particularly monitoring outcomes of kelp restoration (Morris et al. 2020, Eger et al. 2022ab, Earp et al. 2022). This guidance underlines the importance of robust monitoring for all stages of kelp restoration and can benefit those considering restoration in the MaPP region moving forwards.

Kelp aquaculture must take into account many of the same considerations as restoration, as both are focused on identifying sites, conditions, and techniques that optimize the growth of kelp, and so these are treated together in this section. Where additional considerations apply for kelp aquaculture, these are called out separately.

Answering Key Questions to Evaluate the Need for Kelp Restoration

Recent guidance for kelp restoration outlines five key questions that must be answered to determine if kelp restoration is appropriate before restoration should be attempted (Eger et al. 2022ab). These questions are reproduced below and linked to the ways in which the MaPP kelp monitoring project, although not focused on restoration itself, can help to answer these questions.

1. **What are the status and trends of kelp abundance over time?**
2. **What is the spatial and temporal scale of the problem (i.e., what area of kelp has been lost and over what amount of time)?**

   - Kelp populations are naturally highly variable and some seemingly severe local losses may be within the range of natural historical variability for these species – in which case, restoration is not considered to be necessary. Where this variability is beyond the historical range, it may indicate more fundamental changes in kelp forest health and abundance that might warrant restoration.

     MaPP kelp monitoring and supporting activities by collaborators can help to answer questions 1 and 2 because these activities were developed to help understand these status and trends of kelp across different scales for both long-term changes at regional scales (through the study of kelp distribution over time using remote sensing approaches) and short term changes at local scales (with added field monitoring activities).

3. **What are the primary cause(s) of kelp loss in your region? Which are manageable, and which are not?**
4. **Is the system at risk of 'tipping' into an alternative and less desirable state (e.g., urchin barrens), or has it already tipped?**

   - As described in the kelp conceptual model (Section 2), there are many potential physical, biological, and sometimes interacting stressors that may contribute to kelp decline across different spatial and temporal scales. Some of these such as water pollution, sedimentation, and overgrazing or overharvest can be more readily managed at local scales, while others like climate change cannot.

     MaPP kelp monitoring and supporting activities by collaborators can help to answer questions 3 and 4 through guiding questions about drivers of change to kelp and about what other ecosystem components are affected. Current monitoring protocols cover only some of these potential causes of decline, but not others, including protocols for monitoring the state of other ecosystem components but that are not implemented at all sites (see **Section 3.3** for further discussion). However, more robust monitoring designs targeting a wider range of key stressor and ecological indicators could help to answer these questions in ways that are important for management of stressors, which in turn increases the likelihood of success for kelp restoration activities.

5. **What is possible with the available resources and what are the potential resource constraints?**

   - Although this question must be answered primarily by the organization that is planning to pursue restoration, **MaPP kelp monitoring** can create economies of scale if restoration experiments occur near long-term monitoring sites that can help to answer the questions above and also act as control sites where monitoring is already occurring. As part of this question, it will be important to consider how feasible it is to scale up specific interventions over large areas and long timeframes to maintain benefits.

Answering Key Questions About the Design and Evaluation of Kelp Restoration (or Aquaculture)

Study Design: How will we measure the outcomes of kelp restoration? What can we expect and what will we compare it to?

- Key considerations related to study designs, stressors, and influencing factors laid out in this MaPP report will be helpful in study design for restoration.

Site Selection: At what sites do we expect restoration to have the best outcomes based on what we know about kelp in the area? What environmental conditions are necessary for the best restoration outcomes?

- Insights from monitoring by MaPP and its collaborators can help to establish what environmental conditions and stressor levels are like at kelp beds that are doing well, and these insights can be used to inform site selection for potential restoration.
- Considerations for site selection also include considering the future suitability of sites under climate change, which can be informed by reference maps in Error! Reference source not found. of this report, including current climate projections (Error! Reference source not found., Error! Reference source not found., Error! Reference source not found.), MaPP and collaborator field monitoring of sea surface temperature (instantaneous samples, loggers Error! Reference source not found.) to understand local variation and how warming is progressing in comparison to projections, and predicted bottom substrate types which influence the colonization potential of kelp (Error! Reference source not found. and Error! Reference source not found.). For example, although kelp does not readily establish on soft substrates such as sand and pebbles, areas of mixed sand and cobble can act as kelp refugia by providing intermittent hard substrate for kelp while discouraging colonization by urchins which tend to avoid soft substrates as was found to be the case in some parts of Barkley Sound (Gendall 2022, Starko et al. 2022).

Experimental Comparisons: What restoration and/or aquaculture techniques should we try and which will yield the best restoration outcomes? How might outcomes vary by site, ecosystem context, and kelp species? Are other ecosystem components benefiting from restoration?

- To help answer this question, managers can consider using MaPP monitoring sites as control sites and applying standard protocols for MaPP monitoring to restoration treatment and control sites to help increase comparability between the restoration site and other sites.

This could help to increase the overall sample size to better account for influencing and confounding factors with less effort.

- Additional guidance on study design for restoration is available form other sources for specific restoration techniques such as restoration through **urchin control** (e.g., Miller et al. 2020, Lee et al 2021, Ward et all 2022, Warren 2022); **artificial reefs** in areas affected by sedimentation (e.g., Morris et al. 2020, Eger et al. 2022ab), and/or **lab culture**, **seeding, outplanting, and transplanting** using Green Gravel or other techniques (e.g., Carney et al. 2005, Fredrikson et al. 2020, Gleason et al. 2021, Le et al. 2022, and documentation of local restoration efforts listed below). Additional considerations for kelp aquaculture include studies to optimize **aquaculture infrastructure and techniques** for the local context (e.g., Stekoll et al. 2021).
- Additional guidance on establishing the potential **benefits of kelp restoration or aquaculture for the broader ecological community** are also available from other sources (e.g., Bertocci et al 2015, Lang-Wong et al 2023).
- Lastly, managers should also **investigate the possible negative impacts** of any form of kelp culture and transplantation, whether for restoration or aquaculture, on surrounding ecosystems including transmission of disease, alteration of population genetics (particularly whenever non-local broodstock is used), and alteration of the physical environment (Campbell et al. 2019).

Learning from Prior Experiences and Potential Partners

Numerous organizations in B.C. are exploring kelp restoration and/or aquaculture and are likely to offer important locally-relevant lessons learned for MaPP Partners considering restoration in their own communities. Many of these efforts have been well documented while project leads can provide further insights, and some of these individuals or organizations could become valuable advisors or partners for future restoration efforts in the MaPP region. Some of these efforts have included restoration experiments and/or research by:

- **Academic research institutions or partnerships** such as The Kelp Rescue Initiative carrying out academic research on restoration across BC, Ocean Wise Seaforestation Initiative carrying out kelp restoration and monitoring of biodiversity outcomes in Barkley Sound (Lang-Wong et al 2023), Vancouver Island University restoration experiments with bull kelp in the Strait of Georgia, or Simon Fraser University researching the diversity in heat tolerance of kelp and storage of reproductive material in a marine plant 'biobank' a potential source of heat-tolerant kelp spores for use in future climate-resilient restoration efforts.
- **Restoration efforts by community groups**, such as the A-Tlegay Fisheries Society kelp production and restoration pilots funded by BCSRIF, the Comox Valley Project Watershed Society and Nile Creek Enhancement Society efforts at restoring Bull Kelp in the Strait of Georgia.
- **Restoration by industry** as an offsetting measure, such as BC Timber Sales kelp restoration and habitat offsetting efforts at former log sorting sites (Balmer and Wright 2019, North Island College 2020, M.C. Wright and Associates Ltd. 2021).

- **Aquaculture operations and researchers** such as Canadian Kelp Resources, operated by kelp researcher Louis Druhel (also affiliated with the Bamfield Marine Sciences Center) who also offers consulting services, or any number of other private operators across the coast.

3.3 Assessment of Gaps and Opportunities for MaPP Kelp Monitoring

3.3.1 Ability of Current Kelp Monitoring to Address Goals & Guiding Questions

The MaPP Kelp Monitoring Project has made significant progress in these first few years since its initiation. Much of this time has been spent developing and refining standard monitoring protocols, training field crews, working out the logistics of monitoring within each sub-region, and reaching the point of effectively monitoring kelp extent and density through field and aerial methods at selected monitoring sites established across much of the MaPP region. Although the project has only collected a few years of data to date, ongoing monitoring is expected to be able to provide insights into long-term trends in the extent and status and of kelp ecosystems as new data points are added to the time series over the coming years.

However, despite these successes, it is also important to acknowledge the limitations of monitoring to date. **In its current form, MaPP kelp monitoring has not yet realized the intended potential of kelp as a true ecosystem-based management (EBM) indicator and is not yet able to address all of the key Guiding Questions of interest for the project and broader MaPP Partnership**.

This section takes stock of work to date, identifies remaining gaps for fulfilling the intended goals of the project, and provides high-level recommendations for targeted adjustments to kelp monitoring in the future to better meet these goals.

Performance of MaPP kelp monitoring activities can be evaluated against the key criteria for ecosystem monitoring to serve the needs of EBM. As described in Kupschus et al (2016), an EBM monitoring program should:

- **Causally relate the effects of pressures and environmental variability on the ecosystem and services it provides to society**: To date, MaPP kelp monitoring has not carried out extensive monitoring of pressures and has not undertaken the systematic sampling design needed to allow for analyses of causal relationships. Furthermore, protocols and indicators are not explicitly linked to specific monitoring or management questions.
- **Take account of the complex relationships between the ecosystem components of interest, pressures, and environmental variability** – To date, kelp data collected has not undergone extensive analysis other than mapping and summary statistics, and has not been analyzed in the context of environmental influencing factors or other variables of interest.
- **Inform management of pressures with an established causal relationship that are within management control** – To date, kelp data has not systematically informed management decisions, and the lack of analysis for causal relationships with pressures limits the ability to provide a strong rationale for management decisions. Although observations of kelp status and declines in some regions have influenced decisions on harvest referrals, it is

not clear if those decisions were based on data collected by the program at MaPP monitoring sites, or in-season observations of kelp in the broader region.

Performance of MaPP kelp monitoring can also be evaluated by how well it is answering the Guiding Questions for monitoring that were collaboratively developed by MaPP partners at the beginning of the initiative, as summarized in Figure 1 and below in Table 6.

Table 6: Table assessing how well the current MaPP kelp monitoring is doing at answering guiding questions.

MaPP Guiding Questions	MaPP Kelp Monitoring Methods	Progress in Answering Question
 **What do we have?**	TIER 1: linear extent and relative density TIER 2: Areal extent and absolute density Optional Tier1/2 drone imagery	RELATIVELY GOOD PROGRESS MaPP kelp monitoring activities to date have captured primarily **Tier 1** and **Tier 2** information on the state of kelp in the form of data on kelp species composition, extent, persistence, and density using boat-based surveys, drone imagery, and/or satellite image acquisition (as summarized from workshops in Tamburello 2021, 2022). However, Tier 1 and 2 monitoring is not occurring to the same extent in all sites, is lacking from some subregions (e.g., Haida Gwaii, other than Gwaii Haanas NMCA-HHS).
 **How's it doing?**	TIER 1 & 2: Same as above, but for multiple time points to detect trends over a time series.	FAIR Although the most monitoring progress has been achieved for Tier 1 and 2 activities, this monitoring program is relatively young. The oldest surveys reach back to 2018 in the NVI Sub-Region, but most sites have only two to three years of data. Although this is a good start, it is not yet sufficient for the analysis of current trends over time. These monitoring activities should continue to build the time series, but expansion into between-site comparisons can help to provide faster answers to some questions about drivers of change or broader effects on the ecosystem compared to time series analysis.
 **If changing, why?**	TIER 2+: Oceanographic data (boat-based temperature, salinity, visibility, observations on kelp health, and underwater features like urchins, rockfish, substrate)	FAIR to POOR **Tier 2+** protocols do include provisions for monitoring several stressors, with specific protocols for temperature, salinity, water clarity, and bryozoans, as well as provisions for documenting underwater observations of sea urchins (related to mechanical damage stressors) and substrate type (related to sedimentation stressors), but are missing protocols for others such as direct measures of tissue damage, contaminants, nutrients, and algal competition (Thompson et al. 2021). However, there is recognition that protocols should be updated and refined (e.g., updating to include protocols for temperature loggers instead of just instantaneous measurements, updating categories for categorical variables like bryozoan cover to more accurately reflect frequencies encountered in he field, etc.).

MaPP Guiding Questions	MaPP Kelp Monitoring Methods	Progress in Answering Question
		However, in practice, Tier 2+ monitoring is only carried out at a relatively small subset of kelp monitoring sites across the MaPP region and is typically limited to measures of temperature and salinity using fixed data loggers (e.g., Tidbits) and/or instantaneous measurements using a CTD instrument and/or Secchi disk. In some cases, pressures are monitored through other monitoring programs that may intersect with kelp sites, such as nutrient and contaminant monitoring through the North Coast CE Monitoring Program. In addition, based on conversations for this work, kelp data have not to date been analyzed in relation to any of these stressors to search for correlations. Lastly, the rationale for the selection of existing kelp monitoring sites is not well documented – it is likely they were manually selected for importance and feasibility, but may not be adequately distributed to control for confounding factors which would be needed to make conclusions about the causal effects of any given pressure.
 **What else is affected?**	**TIER 3:** Underwater transect surveys of the ecological community of fish and invertebrates at kelp sites (Hakai Protocol)	**POOR TO ABSENT** Some **Tier 3** subtidal monitoring specifically focused on density and biomass estimates of kelp have been completed by Hakai at select sites on the Central Coast as well as by Hakai and Markus Thompson at select sites in North Vancouver Island. However, **Tier 3** monitoring of the broader ecological community of fish and invertebrates within and around kelp beds monitored for MaPP is essentially absent from all sub-regions *except for* community monitoring by Hakai at select Central Coast sites. Other subtidal community surveys have been carried out throughout the region, but generally do not necessarily overlap with current MaPP kelp monitoring sites (with some exceptions – for example, a small minority of standard underwater transects monitored by Wuikinuxv may overlap with monitored kelp sites, per Ken Cripps, pers. comm.). Without community data, it is not possible to analyze changes in other ecosystem components in relation to changes in the status of kelp, or establish causal relationships, both key requirements of a true EBM monitoring program.

3.3.2 Recommendations for Future Kelp Monitoring

This section provides high-level recommendations for how the outcomes of our work for this report can help to fill gaps in current MaPP kelp monitoring activities to support more meaningful contributions of project monitoring data to ecosystem-based management decisions. While these recommendations are relatively high-level in nature, we provide additional context and more detailed guidance for next steps towards implementing some recommendations in Error! Reference source not found..

We recognize that it will not be possible to implement all of these recommendations at once, but they are listed here roughly in the order of suggested implementation and also describe some suggestions for gradual implementation. However, it will ultimately be at the discretion of the MaPP Partners to decide which of these actions are the most important near-term priorities to pursue further and how or when each is pursued.

(1) Improve the effectiveness and coverage of existing baseline monitoring to understand the state of kelp.

- **Support the ongoing implementation of Tier 1 and Tier 2** monitoring at existing monitoring sites to continue building time series.
- **Support the implementation of Tier 2, Tier 2+, and Tier 3 methods** at a larger number of existing monitoring sites to help provide better information about potential influencing factors on changes in kelp state and extent at those sites.
- **Assess the additional funding and capacity that would be needed for MaPP Partners to strategically add protocols and/or monitoring sites** to provide greater coverage of different levels of influencing or confounding factors. At present, most Sub-Regions are monitoring between 1 to 4 sites, while the NVI Sub-Region is an outlier with closer to 7 sites. However, each Sub-Region should have 7 or more sites to adequately detect changes in kelp state while controlling for potential confounding or influencing factors (Markus Thompson, Pers. Comm.) This recommendation is related to **Recommendation 4**, which is about developing more robust sampling designs and potentially adding sites to investigate causal relationships of stressors with kelp while controlling for influencing factors. Although there may not be the capacity to add sites at present, there may be opportunities to do so in the near future with new funding opportunities associated with the implementation of the Marine Protected Area Network in the Northern Shelf Bioregion.

(2) Frame specific monitoring and management questions under the umbrella of each Guiding Question, for each Sub-Region and the overall MaPP Region for priority themes.

- **Develop specific causal monitoring questions for stressors that are relevant for management of the human activities related to those stressors.** Based on the conceptual model and supporting references presented in this report, MaPP Partners will have a stronger evidence base for prioritizing specific pathways of concern for key pressures on kelp ("If Kelp is Changing, Why?").

Among the pressures examined in the conceptual model section, some of these stressors (e.g., temperature, contaminants) are clearly more relevant to management than others (e.g., algal competition). Readers can refer to the Phase II RKMP Monitoring Workshop Report for a more detailed discussion about the development of monitoring questions related to management, with examples. When developing these questions, MaPP Partners should adhere to the PICO guidance for questions relevant to evaluating causal relationships (see Section 3.2.2).

Some examples of these monitoring questions are articulated in each of the Sub-Regional monitoring roadmaps in the following sections of the report.

(3) Review and update MaPP Kelp Monitoring Methods Manual and develop new monitoring protocols where needed to fill gaps in current protocols.

- **Review, revise, and formalize existing MaPP monitoring methods to ensure they are providing the best information possible to answer key questions**:
  - **Review, revise, and / formalize Tier 2+ methods** based on the guidance from this conceptual model and roadmap (e.g., standardize methods for temperature and salinity logger deployment, update and formalize bryozoan cover measurements, etc.)
  - **Formalize documentation of Tier 3 methods** for subtidal kelp and ecological community monitoring that were originally developed by Hakai, and used for Tier 3 surveys in multiple Sub-Regions, into the master MaPP Kelp Monitoring Methods manual. The Hakai subtidal survey methods are available in a public document.
- **Pilot and add alternative methods for sampling of existing kelp indicators** and metrics to get around some of the current operational constraints and inflexibility that limits the monitoring of some indicators and metrics.
  - Evaluate the potential for **monitoring outside of low-tide windows** to reduce the operational constraints created by the need to monitor kelp within a few narrow windows of low-tide time. Recent work out of Dr. Maycira Costa's lab at the University of Victoria has shown that kelp can be successfully detected from aerial or satellite imagery using different wavelengths than conventional surveys and provides some suggested 'correction factors' for interpreting trends in kelp area collected across different tidal heights and current speeds, although comparisons between beds are more likely to be accurate when comparing data from the same tidal height (Timmer 2022).
  - Consider piloting **eDNA methods** for understanding ecological communities around monitored kelp beds. Collection of marine eDNA can be conducted from the surface, which circumvents the issue of limited or absent SCUBA diving capacity as the main limitation for Tier 3 monitoring in most sub-regions and is also relatively cost-effective (e.g., sample processing fees by a private Canadian lab are estimated at $150 per sample).

    Recent piloting of these methods for marine ecosystems in BC makes the application of these methods to MaPP monitoring in the near future much more feasible. First, an ongoing project collaboration between CCIRA and Dr. Caren Helbing's lab at the University of Victoria is assessing dive-based water sampling-based eDNA methods in comparison to conventional diver surveys for assessing rockfish biodiversity on the Central Coast, including the development of DNA primers needed to carry out genetic sequencing that can detect rockfish species native to the BC Coast (Acharya-Patel 2023). Similar studies have been carried out in the Salish Sea for endangered Northern Abalone (Dimon et al. 2022).

Furthermore, the recent development of *passive eDNA sampling* methods for marine environments have proven effective and are much more time and resource efficient than traditional methods of collecting and filtering large amounts of sea water (Bessey et al. 2021). This method has very recently been piloted by the Vancouver Aquarium's OceanWise program for monitoring ecological communities at kelp restoration sites on the West Coast of Vancouver Island (Lang-Wong et al 2023).

Potential eDNA samples could be analyzed by a number of partners in the region with eDNA processing experience, including Dr. Helbing's lab, the OceanWise Program, and the Hakai Institute.

- **Develop monitoring protocols for key pressures missing from current methods**, particularly direct measures of tissue damage, contaminants, nutrients, and potentially algal competition (although the latter has not yet been raised as a pressure of concern within this region).
  - Standard MaPP **protocols for assessing kelp tissue damage** can be adopted from past studies outlined in our conceptual model and stressor summaries (Error! Reference source not found. - Pathway 2: Tissue Damage), and from ongoing work on monitoring the effects of kelp harvesting by Dr. Anne Salomon and students in the North Vancouver Island sub-region. These methods may need to be adapted for the different kelp species.
  - Standard MaPP **protocols for contaminants and nutrients** can be adopted from the North Coast CE monitoring program, which has well-established protocols, which would help to create regional continuity in how these stressors are monitored at kelp sites across the MaPP Region. Additional guidance on sampling design for these specific stressors in other Sub-Regions is also available, for example, the Marine Monitoring Guidance document for water quality which lays out methods and approaches for sampling to capture the effects of nutrients and contaminants from point source versus diffuse source inputs (LGL and MECCS 2019).
  - Importantly, key indicators selected for these new methods should focus on '**decision-relevant indicators'** for the kelp context. These are indicators that are the most directly relevant to the types of management decisions that might be made for kelp or any other managed ecological feature (Delaney et al 2021). In the kelp context, this means indicators that are relevant to decisions related to protection, harvest, restoration, aquaculture, or consumption (BC CDC 2013, Gleason et al. 2021). For example, if the key management decision related to contaminants is kelp food safety for consumption, levels of contaminants measured directly from samples of kelp tissues are more decision-relevant than samples of contaminants collected from the sediment or water column, because it is not clear what the rate of uptake of contaminants from the environment might otherwise be.

(4) Develop more robust sampling designs to enable the evaluation of causal relationships

- **Compile relevant data layers on kelp, environmental variables, stressors, and drivers to inform randomized and spatially balanced sampling designs.** Although there are only a few years of kelp monitoring data so far, there is more than enough information available about the ecology of kelp (via the conceptual model and supporting research) and the state of potential environmental drivers and stressors (from existing data layers on environmental variables and human activities) to develop the types of sampling designs needed to evaluate causal relationships (Kupscus et al 2016). These data layers can provide information about how key variables or pressures vary in space and time so that sites can be selected to cover enough variation in these variables to detect causal relationships for those variables, or other variables for which they might be a confounding factor.

  Some **key data layers that are expected to be useful for the development of future sampling designs** to answer many types of questions about kelp include:

  - **Marine Tidal Speed Data** modelled from field observations for the B.C. Marine Conservation Analysis (BCMCA), and which continues to provide useful information on this key influencing factor for kelp and on other environmental variables and stressors, as noted in our conceptual model. A reference map of this tidal speed layer has been plotted for this report in Error! Reference source not found..
  - **Marine Climate Change Projections** recently developed by the Government of Canada which include historical data and future projections for sea surface temperature, pH, dissolved oxygen, dissolved CO_2, and other variables (Holdsworth et al. 2021). These layers will be helpful for sampling designs to inform monitoring of climate change effects at regional scales, particularly understanding how climate change effects are unfolding compared to model predictions. Reference maps of these projections for one of the most important environmental variables for kelp, sea surface temperature (SST), have been plotted for this report in Error! Reference source not found., Error! Reference source not fo und., and Error! Reference source not found..
  - **Marine Substrate Classification Maps** classifying bottom substrate types at a 100m resolution as modelled from thousands of field observations of the sea floor across multiple areas of the sea floor across BC. (Gregr et al. 2021)
  - **Kelp Historical Extent Map** by Maycira Costa's SPECTRAL Lab at the University of Victoria, which documents the historical distribution of kelp from the mid 1800s to the mid 1900s (Costa et al. 2020). This layer could provide information about sites where kelp was once present and might be successfully restored, although this layer must be cross-references against other environmental data layers relevant for current habitat suitability for kelp.
  - **Kelp Resilience and Bioregional Cluster Analysis** by Maycira Costa's SPECTRAL Lab at the University of Victoria which aims to classify areas of kelp habitat with similar biological and environmental characteristics, including temperature and persistence over time, based on analysis of satellite imagery time series. This type of analysis has, at the time of writing, only been carried out in the Salish Sea and for a small pilot region on the east coast of Haida Gwaii (Gendall 2022). Work is ongoing by a postdoctoral researcher in this lab to extend this kelp resilience analysis to the entire coast of BC.

- **Marine Cumulative Effects Layers** for the marine regions of BC. Such layers developed by Cathryn Clarke-Murray in 2015 (Murray 2015) were used to stratify sampling sites for the North Coast Cumulative Effects Monitoring Program. Notably, at the time of writing, updated marine cumulative effects layers are currently under development by Cathryn Clarke-Murray at DFO that might be useful for future stratification.
- **North Coast Cumulative Effects Program Results** that will provide insights on the localized distributions of key stressors of concern, which could help to assess whether current monitoring sites are covering the full gradient of these stressors to concern and could also help to develop sampling designs for adding sites to more intentionally investigate the potential causal effects of these stressors on kelp. The first current condition assessment report from this program is expected in summer 2023 (Grant Garner, NCSFNSS, pers. comm.).
- **Spatially-Referenced Current Kelp Harvest Volume Data** that is documented by the Province of BC for specific harvest areas. It is not clear whether this information is currently available as a spatial data layer or needs to be compiled from individual harvest records. If it could be made available, a spatial layer of total cumulative harvest across the MaPP Region within and across years could help to inform sampling designs for monitoring to answer questions related to the causal effects of kelp harvest on kelp at broader spatial scales than discrete experiments.
- **Spatial layers of Marine Protected Area Boundaries**, including the footprint of Protected Management Zones within MaPP Spatial Plans, Rockfish Conservation Areas, National Marine Conservation Areas, and new protected areas proposed as part of the Marine Protected Area Network soon to be established on the North Coast of BC. Levels of protection and prohibited activities may need to be controlled for, particularly, for example, when trying to evaluate causal relationships between kelp status and subtidal fish and invertebrate communities that live in and around them. Whether these species are fished or not fished in a given area due to protections will have a significant effect on the outcomes of those analyses.
- **Spatial and Aspatial Indigenous and Local Knowledge** that can capture historical and contemporary community observations of kelp locations, changes, stressors, and harvest as well as the cultural importance of kelp in general and of specific kelp beds or harvest sites in particular. This might be captured through community mapping exercises or interviews as part of Traditional Use Studies (TUS), or may simply be held by individual knowledge keepers. This type of knowledge can help to review, validate, and update other types of information that could inform sampling design.

Sampling designs that take these stressor, drivers, and environmental covariates into account can be used to identify candidate **Sentinel Sites** which are of interest to MaPP Partners (Tamburello 2020). The term Sentinel Site can have many different meanings, but usually refers to sites that are monitored more intensively. In the context of sampling design for investigation of causal relationships, Sentinel Sites might be sites that are important to

Partners, but might also be sites that provide greater opportunities for learning about multiple environmental variables or stressors of interest.

- **Consider the development or adoption of a master sample frame for kelp on the BC coast to help coordinate disparate kelp monitoring activities in the MaPP Region.** MaPP partners could choose to adopt Canada's existing Western Marine Master Sample developed by DFO (described further in Section 3.2.2), which uses a BAS oversample design that allows the addition of new sites. Alternatively, MaPP could choose to develop their own sample frame that builds the sample frame around existing legacy kelp monitoring sites and takes other kelps-specific considerations into account – although these considerations may also be possible to integrate within the existing Western Marine Master Sample.
- **Develop sampling designs for answering specific kelp Guiding Questions about causal relationships (If kelp is changing, why? What else is affected?).** Based on the priority questions and causal relationships identified previously, MaPP Partners can develop sampling designs intended to help answer one or more causal questions related to the effects of key environmental variables or stressors on kelp. Depending on the availability of reference data across the MaPP Region, sampling designs for these questions could be developed at regional scales and subsampled for pilot implementation of new monitoring methods at Sub-Regional and site scales (See related **Recommendation 5** for more information).
- **Have sampling plans in place to make the most of natural experiments.** When unexpected events like marine heat waves, extreme storms, or marine spills occur near kelp monitoring sites in the MaPP Region, they can provide an opportunity for accelerated learning about key stressors to kelp through unplanned 'before and after' study designs. With the benefit of past field data acting capturing the state of kelp 'before' an incident, more intensive sampling immediately after the incident (Stein and Lackey 2012).

(5) Pursue targeted investigation of cause-effect relationships between potential drivers of change, changes in kelp status, and consequences for ecological communities.

- **Identify and implement pilot monitoring for key pressures and ecological responses in select areas**. It will not be possible to implement new monitoring activities for all pressures of interest across all Sub-Regions at the same time due to logistical and capacity considerations. However, different parts of the MaPP Region are particularly well-suited for piloting more intensive monitoring to answer questions about causal relationships due to specific capacity, the existence of other complementary monitoring programs or studies, and/or greater variability in or importance of the key variables of concern (including whether these have been identified as Sub-Regional Monitoring Priorities). Based on our understanding of diverse contexts within the MaPP region from prior RKMP Workshops and further discussions with MaPP Partners and others for this report, we recommend pursuing the following targeted pilot activities.
    - **Questions on Effects of Contaminants and Water Quality:** The **North Coast** Sub-Region is in a unique position to answer questions about contaminants, nutrients, and sedimentation because of its parallel and ongoing Cumulative Effects Monitoring Program, which has some overlap with kelp monitoring sites. The first current condition assessment

report drawing on results from this monitoring program is expected to be released in 2023 and will provide important information for sampling design to more deliberately investigate potential causal relationships for these stressors.

- **Questions on Subtidal Communities:** The **Central Coast and Haida Gwaii** Sub-Regions are uniquely positioned to answer questions about the effects of changes in kelp on subtidal fish and invertebrates given higher local dive survey capacity and existing subtidal monitoring programs. On the Central Coast, these questions might be answered though additional coordination with existing subtidal monitoring programs led by some MaPP Partner Nations (e.g., Wuikinuxv), CCIRA, and Hakai. In Haida Gwaii, these questions might be answered in collaboration with Parks Canada and the Council of the Haida Nation, which carry out subtidal monitoring in Gwaii Haanas NMCA-HHS.
- **Questions on Effects of Harvest:** The **North Vancouver Island (NVI) and Haida Gwaii** Sub-Regions are uniquely positioned to answer questions about stressors related to kelp harvest because of the ongoing research into kelp harvest pressures in these regions and the existence of potential protocols for ongoing monitoring.
    - In the NVI Sub-Region, there is ongoing research to understand the effects of intensive harvest on giant kelp resilience in partnership with large-scale commercial kelp harvesters, Dr. Anne Salomon's lab of Simon Fraser University, Markus Thompson, and MaPP Partners.
    - In the Haida Gwaii Sub-Region, there is ongoing research by a small-scale harvester to understand the effects of small-scale harvest on multiple species of harvested kelp and seaweed with support from BCSRIF funding and in partnership with the Council of the Haida Nation and others.

  Together, these studies could provide a foundation of information for developing monitoring protocols and study designs to answer questions about the impacts of kelp harvesting at multiple scales and levels of intensity across the MaPP region. Once results become available, these discrete studies could be used to develop a more universal MaPP monitoring protocol for both small-scale and large-scale kelp harvests and eventually expanded into ongoing kelp harvest monitoring programs at specific monitoring sites to answer questions about harvest across the MaPP Region.
- **Questions on the Effects of Temperature and Climate Change:** Both current and projected future temperature regimes can be somewhat homogenous within the parts of MaPP Sub-Regions where existing monitoring sites are clustered (see Error! Reference s ource not found., Error! Reference source not found., and Error! Reference source not found.). Although there may be more variation in temperatures at local scales which can be very important for determining kelp outcomes (Starko et al. 2022), it is not clear whether the current number and distribution of sampling sites in each Sub-Region adequately covers local temperature variation or provides enough power for detecting an effect. For this reason, we suggest that the entire **MaPP Region** is best positioned to investigate causal relationships between kelp status and temperature at a regional scale where all sites can be pooled for greater coverage of variability in temperature and other influencing variables, and greater statistical power to detect effects. Reference layers on current and modelled

future temperatures, data from a network of data-loggers deployed within and outside of kelp sites across the coast (Error! Reference source not found.), and both field and a erial/satellite imagery of kelp extent can be used for planning additional monitoring and/or analyses to answer these questions.

(6) Consider the usefulness of MaPP kelp monitoring data for related initiatives and plan to maximize the versatility and broad utility of datasets.

- **Complete the cataloguing of datasets relevant to kelp in BC in the MaPP Metadata Catalogue and make the catalogue publicly accessible to improve the discoverability of this information.** Work to populate the MaPP Metadata Catalogue is ongoing, but could be expanded to include relevant data layers beyond MaPP's kelp monitoring activities – including some of the key reference layers mentioned in **Recommendation 4**. While the data itself does not need to be made publicly accessible in the Metadata Catalogue, having a record that that kind of data is collected along with contact information for the key data steward helps to make sure that other communities, managers, and researchers can discover and ask for appropriate permissions to use that data as part of new studies building up the knowledge base around kelp, where it is deemed acceptable.
- **Coordinate planning for the selection of any additional monitoring sites in the context of existing MaPP Marine Plans and zones as well as the Marine Protected Area Network (MPAN) that will be implemented in the MaPP Region.** Future monitoring through the MaPP kelp program could help to address the goals of both MaPP Marine Plans and compliment additional kelp and subtidal community monitoring that is likely to occur as part of monitoring for the future MPAN. Coordination between these efforts could help to create efficiencies for kelp monitoring and help to overcome some of the capacity, time, and budget constraints that currently limit more extensive kelp monitoring by MaPP Partners within the region. The use of a master sample frame, as described in **Section 3.2.2**, would be helpful for coordinating kelp monitoring activities between the MaPP Partners and other entities carrying out monitoring for kelp and other indicators as part of marine protected area network monitoring or other monitoring programs.
- **Consider the importance of existing and future kelp monitoring sites as treatment or control sites for management interventions at other kelp or non-kelp sites.** As communities in the region become increasingly interested in the trial and mainstream implementation of management interventions related to kelp, existing kelp monitoring sites could be useful treatment and/or control sites. For example, new sample sites for 'treatment' through restoration or experimental harvest could be selected at other kelp sites that are manually or statistically "matched" to environmental conditions at MaPP kelp sites which can act as controls where no action takes place. Using existing monitoring sites as treatment and/or control sites creates efficiencies in that some baseline "before" data already exists for these sites, ongoing monitoring activities can provide "after" data at these sites at no additional cost, and the use of MaPP sites as strictly control sites maintains continuity in the existing time series.

From this point onwards, it will be up to the MaPP Regional Team and the MaPP Sub-Regions to review the recommendations within this report, assess recommendations against near-term priorities and resource constraints, and choose those recommendations to include as part of the development of their Sub-Regional Kelp Monitoring Strategies.

Once priorities are chosen, MaPP Partners and Collaborators can work together to identify the right people, strategies, and resources to bring to bear to help develop kelp monitoring into a true EBM monitoring program capable of informing robust, evidence-based management decisions across the region. Overall, we believe that the implementation of some or all of these recommendations will provide a much stronger foundation for decision-making about the management of kelp ecosystems moving forward.

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