ISS 2025 - Workshop 5 Final Report

Exploring Needs and Opportunities for Improved Monitoring of the Benefits and Impacts of Seaweed Farming in Alaska and British Columbia

August 18 2025

Workshop details: Sunday, May 4, 2025 | 9:00 AM – 12:30 PM | Victoria Conference Centre

SUGGESTED CITATION: Gutzmann, S., Gillies, E., Tamburello, N., Cypher, A., (2025). Exploring Needs and Opportunities for Improved Monitoring of the Benefits and Impacts of Seaweed Farming in Alaska and British Columbia. Workshop Report. International Seaweed Symposium 2025. Victoria, BC, Canada.

Project Background & Objectives

Seaweed farming is an ancient tradition that is now experiencing rapid expansion across the globe due to growing interest in its potential economic, ecological, and climate change benefits. While 97% of current production is within Asia, seaweed farming in North America has likewise been expanding, with harvest in Alaska [AK] swelling from less than 50,000 pounds in 2017 to nearly 900,000 pounds in 2022 (Kim et al. 2019; Kotowicz et al. 2024; NOAA 2024), and harvests from British Columbia [BC]'s largest commercial producer alone growing from roughly 110,000 pounds in 2022 to an estimated 441,000 in 2023 (Jones 2023; Buckner et al. 2023). There is growing interest in the sector for both northern and southern waters of the region.

Ensuring sustainability of the sector during a period of accelerating growth requires a deliberate approach to environmental monitoring of the sector's anticipated ecological benefits and impacts to inform progress towards sustainable development and management goals. There have been recent efforts to establish monitoring and evaluation frameworks for this sector (e.g., TNC 2024). However, a more comprehensive and locally relevant approach to ecological monitoring of the seaweed farming sector in AK and BC is needed to inform future monitoring guidelines and operational requirements that can support the sustainable growth of the sector as it scales.

To address this need, expert practitioners from ESSA Technologies Ltd. (ESSA) in BC and the Prince William Sound Science Center (PWSSC) and NOAA's Alaska Fisheries Science Center in AK were retained by the Pew Charitable Trusts to:

- Develop **environmental indicators and metrics** for seaweed farming in AK and BC;
- Summarize **key benefits and impacts** of seaweed farming in the region;
- Summarize ongoing **monitoring programs and data sources**; and
- Highlight data and **knowledge gaps** and lessons learned.

Our research process is divided into three main tasks:

1. Reviewing the literature and documenting references, environmental impacts and benefits, potential indicators, and data sources in Excel catalogues;
2. Engaging with seaweed practitioners and knowledge holders in AK and BC; and
3. Synthesizing findings and recommendations in a Monitoring Framework report.

To help inform the effort, a half-day workshop at the International Seaweed Symposium (2025, Victoria, BC) convened practitioners, regulators, and experts working on seaweed ecology and farming and discussed how and where improvements in monitoring could be made to better assess the environmental benefits and impacts of seaweed farms in the region. This workshop included an opening presentation on the current status of seaweed farming, emerging sustainability themes, and existing datasets in BC and AK, and was followed by a series of interactive group brainstorming breakouts. The presentation slides can be found here, and the full workshop agenda can be found here. This report is a summary of the workshop.

We note that this project focuses on Western Science methods, and to remedy this bias, our work is advancing alongside a parallel project that aims to engage and uplift regional Indigenous voices to explore how Indigenous knowledge and scholarship can guide and be reflected in the seaweed farming and monitoring space to better serve the needs of Indigenous communities.

Workshop Summary

Background Context

The BC and AK coast span more than 132,000 km combined within the cold, temperate Northeast Pacific Ocean. With frequent inclement weather, this region has an expansive and remote geography and is a naturally productive ecosystem for seaweeds. Upwelling currents deliver cold water and abundant nutrients that support nearly 600 macroalgal species (Druehl & Clarkston, 2016). However, this seascape is also experiencing climate change, human and economic development (ranging from populated cities to remote, small communities), and recovering sea otter populations.

Seaweeds have been stewarded by Indigenous Peoples in AK and BC for at least 14,000 years, and they have been used for food, medicine, materials, and as a cultural relation for generations. For example, in BC, bull kelp was used by Kwakiutl in ceremony and to carry eulachon grease for making rope, fishing line, and harpoon lines (Gutzmann 2023). In AK, the Tsimshian used black seaweed as a poultice to control bleeding and treat cuts (Hansen 2023). In addition, ancestral tending of kelp included transplanting kelp to promote roe-on-kelp fisheries, as well as clearing kelp to corral salmon (Stewart 1977).

British Columbia

Despite the long history of people and seaweed, the contemporary seaweed farming sector in BC is quite young. In 2012, just two seaweed cultivation companies held tenure (Figure 1), and as of 2024, there were 21 active licences (internal dataset, Province of British Columbia). Moreover, the seaweed farming industry's production varies widely. For example, annual cultivation harvests between 2012 and 2022 ranged from one to 18,000 kg WW. While the objective of cultivation companies also varies (e.g., from growing for restoration purposes to the sale of seaweed biomass), market demand generally remains a key limiting factor for the seaweed farming industry in BC.

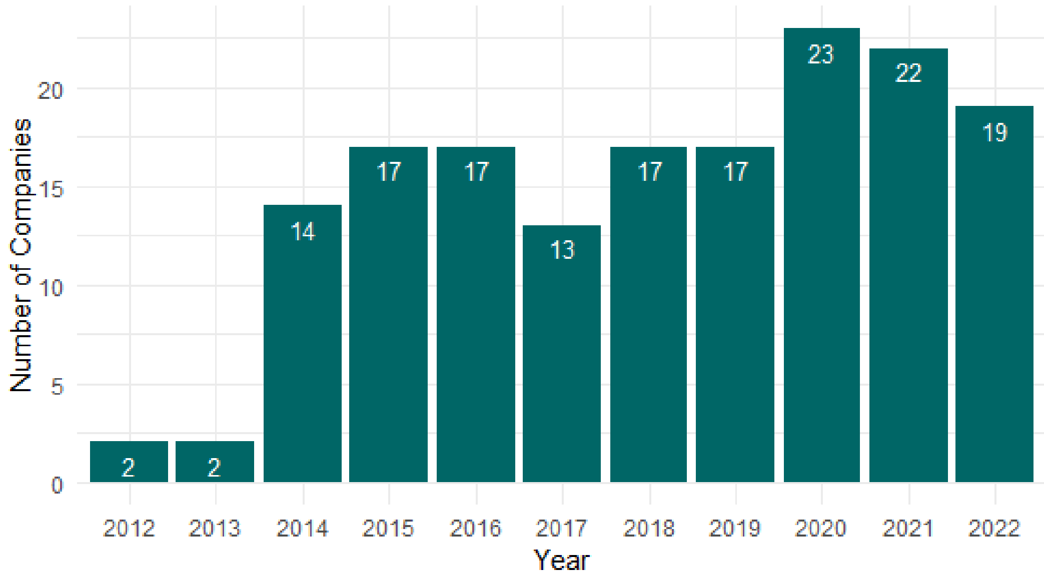

Figure 1: Number of seaweed farming companies with tenure from 2012 to 2022 (internal dataset, Province of British Columbia).

While data availability on seaweed farming operations with active tenure in BC is patchy, available data on seaweed farms shows that they range from ~2 - 42 ha and are mostly located in the southern part of the province (Figure 2).

Figure 2: Map of 13 seaweed farming tenures in BC (data as of 2024).

In BC, the main seaweed species cultivated are all kelps, specifically *Saccharina latissima* (aka

Saccharina groenlandica; sugar kelp, split kelp), *Nereocystis luetkeana* (bull kelp), *Alaria marginata* (winged kelp, ribbon kelp), and *Macrocystis pyrifera* (giant kelp) (internal dataset, Province of British Columbia). These kelps are usually cultivated on longlines anchored at about 3-m depth over soft sediments (Martone et al. 2025). The maximum depth of farms is typically 40 m due to the costs of anchoring systems in deeper waters (Martone et al. 2025). Farming preparation begins in the fall when wild kelp trimmings are collected for their spores (Jones 2023). To reduce the possibility of genetic mixing, the province has guidelines for seaweed spores to be sourced from at least 30 individuals within a 50-km radius of the farm (Jones, 2023; LGL 2024). Seaweed growth then occurs during the winter months, and by March or April the fronds are ready for harvest (Jones 2023).

The policies and regulations governing the practice of seaweed farming are still in the early stages of development in BC. Presently, seaweed farming is regulated at multiple levels via a harmonized review process (Figure 3). At the provincial level, seaweed farming licences are issued under the *BC Fish and Seafood Act* (FSA) for seaweed that is intended for human consumption (and infrastructure under the *Land Act*) by the BC Ministry of Water, Land and Resource Stewardship (WLRS). Fisheries and Oceans Canada (DFO), a department of the federal government, issues shellfish and finfish Aquaculture Licences. WLRS and DFO co-regulate any aquatic plant culture sites that co-occur with shellfish or fish aquaculture. Moreover, DFO regulates through the *Fisheries Act* any applications with potential impacts to fish and fish habitat (for example, sites where there could be herring spawning occurring on cultured kelp) and/or the *Species at Risk Act*. Finally, Transport Canada (also a federal government department) reviews any aquaculture applications that are in navigable waters.

In BC, there is a review and referral process for aquaculture developments in First Nations territories (Pawluk & Outhwaite 2024). This allows First Nations' governing bodies to review potential impacts, raise concerns, and propose mitigation measures. The process often involves shared decision-making, guided by co-governance agreements or reconciliation protocols between First Nations and the province.

BC does not yet have a specific marine plant aquaculture policy, but in general, the seaweed farming space intersects with much of the broader marine policy development currently underway. For instance, seaweed aquaculture sits within the broader context of Blue Economy planning in Canada, which is in its initial stages, as well as various international commitments (e.g., Paris Agreement, 2030 Agenda) (Gutzmann & Cisneros-Montemayor *in prep*). The Province of BC has also developed a BC Coastal Marine Strategy, which is the province's first shared, coastwide vision for the stewardship of marine resources (Province of BC 2024).

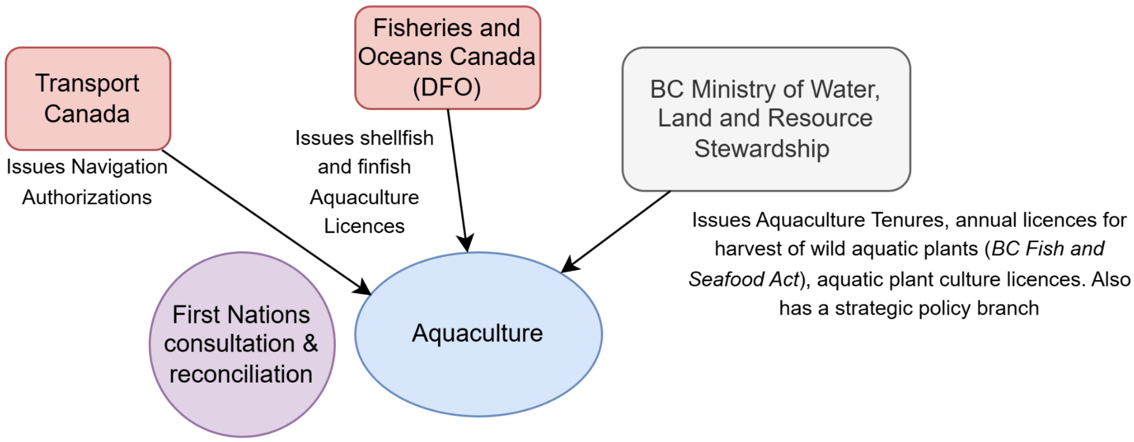

Figure 3: Seaweed regulatory landscape in BC. Diagram adapted public talk given by representatives from the Province of BC (Pawluk & Outhwaite 2024).

Alaska

The state of Alaska is an ideal location for expansion of the farming industry as it has more mileage of coastline than the lower 48 states combined, as well as cold, nutrient-rich waters. Existing infrastructure for fishing industries can also be adapted for use in seaweed farming. While active farms and farm leases are prevalent from southeast to western AK, there remains a need for a market. AK seaweed farming began in 2017 and peaked in 2022, as many farmers have since been unable to sell crops and have downscaled or rescinded their leases.

In 2016, the Alaska Mariculture Task Force was formed and tasked with identifying needs for a viable mariculture industry in AK. Today, the Alaska Mariculture Alliance, a group of mariculture stakeholders, continues to identify needs and address bottlenecks to growth of the mariculture industry. Federal funding has been a key player in advancing mariculture in recent years. Awards like the Build Back Better Regional Challenge to Southeast Conference and *Exxon Valdez* Oil Spill Trustee Council to Mariculture research programs have brought in over $80 million in funding. AK faces unique challenges that restrict growth of the mariculture industry, including limited road access, expensive export costs, and high utility costs.

Alaskan seaweed farms primarily grow sugar, ribbon, and bull kelp, utilizing multi-line arrays and catenary arrays. Farming is regulated by the Alaska Department of Fish and Game and Alaska Department of Natural Resources, which enforce leases and guidelines such as the 50-50 rule. The 50-50 rule states that farmers must collect 50 adult, fertile kelp within 50 km of their leased farm and re-inoculate their farm each year from fresh sori. Gametophyte culture is not permitted. In general, there is concern in AK about how farm expansion will affect fish populations and whether farms will disrupt other resource users and sectors (e.g., fishing, recreation, tourism).

Monitoring Context

In BC, existing regulations do not require much monitoring and reporting for licensed seafood growers (Martone et al. 2025). As such, most of the current research and monitoring on seaweed farming in BC is from the academic and grey literature. There are no regional, long-term seaweed aquaculture monitoring programs at present, although there are several that focus on wild seaweeds and marine ecosystems. These include programs like: BC Shorezone, which maps nearshore coastlines in BC; the Marine Plan Partnership for the North Pacific Coast (MaPP) Regional Kelp Monitoring Program, a community-based wild kelp monitoring program focused on giant kelp and bull kelp under a collaborative governance structure that brings together 17 First Nations and the Government of BC; the Hakai Institute's remote sensing of wild kelp; Sentinels of Change, a project driven by communities and scientists from across coastal BC, which investigates invertebrate recruitment and biodiversity, including around wild kelp beds; and the Coastal Stewardship Network Regional Monitoring System, which provides digital data collection tools for First Nations monitoring coastal regions.

In AK, research and monitoring tends to be more mariculture-focused than in BC. The *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) funds several mariculture programs, including the Mariculture Restoration and Research Consortium (ReCon) program. This program collects data on water biogeochemistry, nutrients, zooplankton, wildlife (birds, fish, marine mammals) interactions with farms, and benthic effects from several mariculture sites. There are also numerous non-mariculture focused monitoring programs in Alaska, including the EVOSTC-funded Gulf Watch Alaska program, the National Research Foundation (NSF)-funded Northern Gulf of Alaska Long-term Ecological Research (NGA-LTER) program, the Alaska Ocean Observing System, Global Ocean Ecosystem Dynamics (GLOBEC) program, and many others.

Globally, there are several prior efforts to develop monitoring frameworks for both wild and farmed seaweed (e.g., Eger et al. 2024; Byron et al 2024; TNC 2024; Clark et al. 2021). However, these efforts have been focused on different environmental contexts. For instance, they often detail monitoring on more tropical or accessible farms, focus on only a subset of possible effects, or are intended for wild seaweed beds.

Monitoring itself can be carried out by a wide range of participants in the sector, depending on their capacity, including growers and cooperatives, Indigenous Guardians and stewardship departments, managers and regulators, and researchers in academia or the non-profit sector. Beyond tracking the environmental effects of farms for conservation and compliance purposes, environmental monitoring can also have spin-off benefits for decision making across a wide range of actors involved in seaweed farming activities, from optimizing productions to supporting social licence and regulation (Table 1), but it typically is restricted by limited resources.

Table 1: Key decisions along a spectrum of decision makers that can be informed by environmental monitoring.

<table>
<tr><th>Grower/Cooperative</th><th>Manager / Regulator</th></tr>
<tr><td>Site selection
Species to cultivate
Farm design and orientation
Seed stock selection / hatchery production
Outplant/harvest timing
End use and market development
Social licence</td><td>Application review
Conditions of licence/permits, potentially including:
Area restrictions
Design requirements
Seed stock selection requirements
Monitoring requirements
Managing sectoral-scale growth and environmental effects
Social licence</td></tr>
</table>

Workshop Details

This project aims to address the need for seaweed farming monitoring guidance specific to BC and AK. The overarching workshop goals were to apply participants' collective knowledge to:

1. Narrow down which core indicators to focus on
2. Provide some initial ideas on how best to monitor them

The workshop was broken into two parts:

1. Indicator selection, in which participants were asked to:
   - Review and narrow down a long-list of candidate indicators
   - Review potential effects within this theme and comment on indicators / add others in the context of BC and AK
   - Consider candidate indicators in light of selection criteria, including relevance for decision making
   - Filter and sort to propose 2-3 core indicators per theme
   - Discuss and document rationale
2. Monitoring method & design considerations, in which were participants were asked to discuss and document the following for their top 2-3 chosen indicators:
   - WHAT indicator did you choose?
   - WHY is it useful? Links to decision-making?
   - HOW methods / tools / knowledge can address core indicators within / across sites? Are there existing protocols?
   - WHO is best able to monitor these indicators - growers / regulators / researchers? Who is best positioned to do this in BC / AK?

Workshop participants were further divided into two themes: Biotic indicators and abiotic/pollution indicators. Groups swapped themes halfway so that all participants discussed each theme. Participants are gratefully acknowledged for their participation and contributions. The list of participants is in **Appendix A**, and the list of presented indicators is in **Appendix B**.

Workshop Findings

Summary: Biotic Indicators

For biotic indicators, both groups highlighted the importance of biodiversity, genetic, and pest (epifauna/disease) monitoring overall, although the groupings in which these indicators were placed varied (see tables below).

Biodiversity

Biodiversity is both an indicator and a metric for monitoring, a complexity that was discussed by both groups. Participants highlighted the importance of being specific and targeted in biodiversity monitoring so that it is not used as a “catch-all” (metrics can be seasonal and local to allow flexibility). Participants noted that biodiversity monitoring should consider the ‘change in biodiversity’ versus absolute biodiversity, as some areas are naturally lower in biodiversity than others. Both groups landed on a grouping of metrics to represent biodiversity (see Tables 2, 5, and 6):

- Group 1 grouped fish, benthic (bottom) invertebrates, and understory kelps into an indicator called “fish & benthics” (Table 2).
- Group 2 included biodiversity within a category called “habitat alteration” (referring to both habitat enhancement and habitat disturbance) (Table 3), as well as a group called “community alternation” (referring to epibiota habitat use and biodiversity, biofouling, benthic species habitat use and biodiversity, and invasive species risk) (Table 4). Group 2 also highlighted benthic invertebrates and fish as being important to monitor.

Rationales for focusing on fish and benthic invertebrates included that fish and benthic impacts are relevant to other user-groups (not just seaweed farmers) and that these are practical metrics that can be used by the seaweed farming industry to increase social licence. Participants discussed how habitat provided by seaweed farms for fish biodiversity is highly variable and depends in part on the type and timing of kelp being grown, the quantity harvested versus left on the lines, as well as the fish species of interest (e.g., Bates et al. 2024). Internationally, it was noted that seaweed farming creates fisheries spillover benefits for localized purse seines for some species such as haddock, lance, mackerel, sand eels, and pollock. Similarly, more kelp can supplement the diets of and increase productivity for benthic invertebrates (e.g., urchins), potentially reducing feeding pressure on wild beds and leading to positive impacts on associated fisheries. Alternatively, fished species may be, or may be perceived to be, negatively impacted. For example, participants shared that there is concern in Prince Rupert, BC, surrounding the displacement of Dungeness Crab and/or fisheries for them. Similarly, in AK participants noted concern over seaweed farming's impacts to accessing economically viable species such as sea cucumber.

Participants also noted that while collecting eDNA is pretty straightforward, sample processing and analysis in commercial labs can be expensive and interpretation can be limited. Thus, eDNA for biodiversity monitoring should perhaps be conducted by non-farmers in the form of focused research.

Table 2: Group 1 fish & benthic prioritized indicator and monitoring methods.

What?	Fish & Benthic
Why?	• Economic and cultural importance • High importance • Shape public opinion • Understand ecological interactions (facilitation, competition, predation)
How?	• Technology – cameras / AI • Dive (maybe) – good for benthic, okay for fish • ROV – benthic kelp survey • eDNA (ARMS or water sample) • Trapping (e.g., crab traps) • SMRFs • Fish tagging • Sportfishing (smaller commercial invertebrate fisheries)
Who?	• Farmers • Academic researchers • First Nations Guardians / marine stewardship teams • Federal fisheries agencies (e.g., DFO, NOAA) • Consultancies • Robots / automated systems

Table 3: Group 2 habitat alteration prioritized indicator and monitoring methods.

What?	**Habitat Alteration** → habitat enhancement (refugia use, structural diversity), habitat disturbance (human activity from monitoring and farm maintenance)
Why?	● Maintain / improve ecosystem integrity and productivity (health)
How?	● Comparison to baselines and reference sites (controls) ○ Seasonal and annual ● Community composition: Invertebrates, fish, algae, benthic communities (infaunal / epifaunal) ● Habitat use / behaviour
Who?	● Collaboration across government, farmers, researchers, etc. ● Guardians from First Nations - snorkel surveys ● Citizen science (i.e., recreational divers) for reference sites

Table 4: Group 2 community alteration prioritized indicator and monitoring methods.

What?	**Community Alteration** → on and under farm → includes epibiota habitat use and biodiversity, biofouling, benthic (bottom) species habitat use and biodiversity, and invasive species risk
Why?	● Is the impact of farming spreading to the local community, or is it localized?
How?	● Direct sampling kelps (farmed vs wild populations) and structures of farms ● Benthic samples ● Biodiversity indices – as many as possible so replicable ● Video of benthic or grabs
Who?	● Farmers (as this affects harvest) ○ On-farm, but less feasible for adjacent wild populations – this would be more feasibly via collaboration with cooperatives, researchers, or community groups ○ Depending on the scale of the farm, these activities could fall under cost of production / cost of doing business

Biosecurity / community alterations

Both groups agreed that monitoring should be done to determine whether seaweed farms contribute to increased abundance or aggregations of disease and/or undesirable species (native or invasive), which can have implications for both wild seaweed and the farmed product (yield, quality, etc.)(e.g., Good et al. 2021). Again, both groups landed on a metric grouping (see Tables 4 and 5):

- Group 1 called this group epibiotic pests & diseases (biosecurity) (Table 5).
- Group 2 considered this within “community alterations” (Table 4).

In BC and AK, pest species may include bryozoans. Participants also noted observations of a univalve shellfish that eats through farmed kelp but has not been observed as an issue for wild kelps. It was noted that disease and pests may be particularly important as the industry scales up, similar to the forestry sector. However, participants felt that knowledge of seaweed diseases and pests in BC and AK is generally lacking.

Table 5: Group 1 epibiotic pests & diseases prioritized indicator and monitoring methods.

What?	Epibiotic pests & diseases
Why?	● Links to both kelp health for farmers & ecosystems ● Could have major impacts as sector scales up and with climate change ● Potential major risk for wild kelp and economic losses
How?	● Standardized monitoring protocols for farmers for epibiota or disease features that are visible and easily identified (area-specific species / disease risk) ● Protocol / avenue for getting potential disease / microbiological pest samples from farm to identification lab ● Generational and local → regional monitoring network to communicate and share monitoring data
Who?	● Farmers in collaboration with researchers / institutions – local → regional ● Farmers/researchers collect samples and send to research / government institutions for analyses and reporting back ● Create a network to allow farmers to upload and see each other's data to help each other out. Scalable system.

Genetics

Genetic diversity was discussed by both groups but prioritized as an indicator by Group 1 (Table 6). Both groups agreed that this indicator would be difficult to monitor but were divided on the perceived importance of genetic monitoring in BC and AK specifically because of the precautionary guidance/policy around the 50x50 (AK) or 30x50 (BC) rule (i.e., seaweed source material must be collected from 50 (in AK) or 30 (in BC) individuals within 50 km of the proposed farm site).

Participants who felt that genetics are particularly important for ongoing monitoring referenced farm-scale crop failures that have occurred in tropical regions due to disease (e.g., ice-ice disease, see Ward et al. 2022 for example) because of low genetic diversity within seaweed cultivars (i.e., on-farm genetic diversity). Further, they noted that local seaweeds in BC and AK are locally adapted and so they would like to avoid genetic mixing of farmed species with wild populations (i.e., off-farm genetic diversity) because genetic diversity will be particularly important for resilience to climate change.

Others felt that ongoing monitoring for genetic diversity is less important because it is protected by the 50x50 rule in AK and 30x50 rule in BC; however, they acknowledged that these rules may need to be refined for 1) localized genetic diversity and/or 2) by species (e.g., bull kelps are more susceptible to temperature because their reproductive tissue is at the surface, so there is the potential for higher localized genetic diversity [~5km]). A participant suggested following the bioregion/genetic region (rather than a set distance), an approach that has been used in Tasmania.

Overall, participants felt that there is not a good sense of genetic diversity within wild seaweed populations in BC and AK to begin with, although recent work is beginning to fill this gap (e.g., sugar kelp - Grant and Chenowith 2021, giant kelp and bull kelp - Gierke et al. 2023, Bemmels et al. 2025). They also felt that it is important to consider socio-economic factors; for example, farmers have noted that 50x50 regulation and 30x50 guidelines can be financially and logistically difficult, if not prohibitive. Further research and public outreach on existing research of genetic diversity, as well as the social-ecological implications of gametophyte propagation compared to current 50/30x50 guidelines, is needed in BC and AK (e.g., Gruenthal and Habicht 2022).

Table 6: Group 1 genetic diversity prioritized indicator and monitoring methods.

What?	Genetic diversity
Why?	● To protect the genetic diversity of wild seaweed ecosystems and improve adaptation chances to future challenges
How?	● Sampling and genetic analysis of wild seaweed populations: ○ from different regions ○ before and after introduction of a seaweed farm
Who?	● Biologists (students) for testing ● Government funding and /or labs ● Guardian programs, wild harvesters, etc. for sample collecting

Other biotic monitoring considerations

Impacts from movement and dragging of infrastructure may be site specific. For instance, in AK, permits require that gear is removed at the end of season, while in BC, workshop participants noted that most farms remove longlines after harvest but leave mooring lines in the water.

Monitoring for phyto/zooplankton has synergies with monitoring done during farm operations on phyto/epibiotic species because plankton has an impact on farm growth, success, and product.

Entanglement, while important for social licence, has not been documented on seaweed farms in this region. There are about five documented cases in the literature globally (dugongs and turtles). Moreover, participants expected entanglement to be dependent on the location and the size of the farm (e.g., high potential if the farm is sited in feeding grounds or other important areas). Because this is mitigated primarily through the seaweed farm permitting processes, and partly through choice of farm materials (e.g., rigid breakaway lines) groups determined that it may be less important for ongoing monitoring than other indicators. However, documenting positive/negative interactions with farms by birds and mammals may be more important in specific locations (e.g., near an Important Bird Area vs. elsewhere) or for specific species (e.g., species at risk). In addition, entanglement may be an easy add-on to a monitoring framework for a few reasons:

- Mammal/bird entanglement would be relatively obvious to farmers, and so reporting this could be a simple addition to standard farm operations (e.g., what do you see at the farm, or on the way to the farm). Furthermore, for marine mammals, reporting entanglements is required in both Canada and the US.

- Cameras and AI could also be used to document mammals and bird interactions with farms (e.g., birds feeding off of mussels on farm infrastructure).

Participants noted that people see a lot of things on the farms but they don’t necessarily write it down. These opportunistic observations could be compiled (e.g., via existing monitoring / reporting apps) and shared with a central database, creating an alert system for other farmers. An observation network would be useful for farmers to know who to ask for expertise/experience with novel observations or conditions.

Summary: Abiotic Indicators

For abiotic indicators, those that anchored the discussion in Group 2 were plastic pollution (including microplastics), carbon storage, sediment composition, acidification, nutrient provision, and bioaccumulation & biomagnification. In Group 1, many of these same indicators were discussed, as well as wave energy and light penetration. Nutrient provision and carbon storage were seen as generally important to monitor for both groups but were not explored further during the session because participants felt that they were more difficult to monitor and to attribute changes to farming activities than other indicators. However, nutrient accumulation in seaweed samples was noted in Group 2’s bioaccumulation indicator. Prioritized indicators are discussed further in the sections below.

Light and water flow

Participants felt that many of the indicators were important but that some would be difficult to monitor (e.g., carbon storage, sediment composition, acidification). One participant argued that indicators such as light penetration, flow, and salinity would be simpler to monitor and suggested that a monitoring program focus on those initially but could later add more complex indicators, suggesting benefits of a tiered or staged approach to monitoring. Group 1 chose to prioritize light penetration (Table 7) and wave attenuation / flow alteration (Table 8), while Group 2 discussed these indicators but did not prioritize them.

There were differing opinions regarding light penetration: Some participants thought that the shading effect of farms could be important for benthic communities, while others expressed that, in their experience, light attenuation does not seem significant at farm sites, especially given that kelp is only in the water for half of the year. That said, participants agreed that it was easier to monitor than other indicators, with some describing it as “low-hanging fruit to monitor.” Sensor loggers could be used to monitor light levels at different depths, while remotely operated vehicles (ROVs) and divers could be used for benthic surveys. Artificial intelligence could be used to automate species identification in videos, although this technology is still generally experimental, expensive, and sometimes proprietary at the time of writing.

Participants noted the importance of understanding how seaweed farms affect water flow given that changes to flow can affect the path of migrating species (like salmon) and kelp growth. In addition, seaweed farms could buffer impacts from vessel wakes on sensitive coastal habitats. Devices like accelerometers and wave buoys, which are cheap and accessible, could be used to monitor water flow and directionality. Participants also discussed using acoustic doppler current profilers (ADCPs) and remote sensing to help monitor wave attenuation and effects of farms on local water circulation.

Table 7: Group 1 light attenuation prioritized indicator and monitoring methods.

What?	Light attenuation
Why?	• Currently in BC, don't site over understory kelp, eelgrass, natural kelp beds. What about other benthics? • Early research could inform scale-dependent monitoring conditions of licence

How?	• Light sensors, loggers (CTDs)
	    ○ Possibly at different depths, different locations around farm, track edge effects, control site
	• Pair with benthic surveys (existing DFO benthic monitoring)
	• ROVs or divers
	    ○ ROVs once a year at this scale not currently seeing many impacts in BC/AK
	• Drop cameras (e.g., 'GoPro on a stick')

Who?	• Farmers can do sensors / drop cameras; others would be researchers • Automated image analysis ○ University of Victoria computer engineering students working on automated image analysis for ROV footage

Table 8: Group 1 wave attenuation / flow alteration prioritized indicator and monitoring methods.

What?	Wave attenuation / flow alteration

Why?	• Site selection
	    ○ Harbours
	    ○ Sensitive coastal habitats / heritage farms
	• Understanding impacts on migrating and resident species using flow as cues

How?	• Wave buoys • Accelerometer and Raspberry Pi microcomputer assemblages on farms • Can this be remotely sensed? ○ Wave/current/tides → Maycira Costa's lab working on satellite extraction of these variables • How to place on farms and design on buoys to measure flow both 1) internal to farms and 2) attenuation across/behind farm in larger environment • Clod cards (erodible plaster blocks yielding coarse insights into total flow and direction) • Complementary methods – e.g., multiple ADCPs around farms

Who?	• *Didn't really get to the "who" – more had a discussion about scale:*
	• So many farms affected by scale → what is small, medium, large?
	    ○ Cascadia is under 4 ha; Metlakatla up to 40 ha, possibly 100 (not one giant farm but distribute across four smaller farms)
	    ○ Maine has some guidance for max 40 ha, but little research
	    ○ France planning 300 ha farms – plans for distance from wild kelp beds

Pollution

Discussions around pollution generally centred around plastic pollution and bioaccumulation in farmed seaweed, and the importance of sampling not only to measure the uptake of contaminants from the water (thus leading to environmental benefits like water quality improvement), but also to ensure seaweed quality and safety, which is particularly important if the seaweed product is being used for human consumption. Microplastics could also be ingested by livestock, which could then be eaten and accumulated by humans. Group 1 discussed both of these topics and although they did not prioritize plastic pollution as an indicator, they did prioritize bioaccumulation (note that no table provided as Group 1 ran out of time to explore it in depth). Meanwhile, Group 2 prioritized plastic pollution specifically (Table 9) and bioaccumulation more broadly as an indicator (Table 10).

In terms of plastic pollution, participants from both groups noted that monitoring marine debris would likely be important for social licence. Aside from farms getting swept away (and lines then degrading in the environment and contributing to microplastic pollution), participants did not believe that seaweed farms pose much risk of other forms of plastic pollution. Participants noted that while shellfish and finfish farms have records of both microplastic and macroplastic pollution from cage designs, the sources of these plastics are not present for seaweed. However, participants did note the importance of monitoring plastic pollution for not only better understanding seaweed farming's contribution to plastic pollution, but also the effects of plastic pollution on seaweed farming (e.g., debris from fishing getting trapped in kelp farms).

Participants chose to explore plastic pollution as an indicator largely because of the feasibility of doing so. Available methods include visual surveys for larger plastic debris as well as water and sediment sampling for microplastics. However, participants from Group 1 noted that sediment sampling can be technically difficult and expensive to process and not suited to farmer-led monitoring. One participant noted that monitoring for plastic pollution could be potentially contentious if the goal is attributing plastics to farms, which could be difficult, especially in fishing towns where there may be confounding sources of plastic pollution, such as from lost or discarded fishing gear. Aside from monitoring, participants discussed the emerging use of natural materials for kelp farm infrastructure to reduce the risk of plastic pollution from lines.

In terms of contaminant bioaccumulation, participants in Group 1 discussed the potential role of seaweed farming in restoring water quality due to seaweeds' ability to absorb and thus bioremediate contaminants in the marine environment (e.g., one participant noted regular use of seaweeds to remediate heavy metals from antifouling paints in marinas in Scandinavia). Testing seaweeds is not broadly required in BC/AK, but one harvester mentioned that they voluntarily test for contaminants, and that the cost of testing is ~$100 per seaweed sample to test for metals. However, another participant noted that sampling for heavy metals is $1000 / sample. In general, participants felt that the affordability of sampling for farmers would depend on the market. Participants in Group 2 shared that farmers are interested in knowing about heavy metal bioaccumulation, and that monitoring this could be relatively simple because tissue samples are already taken regularly and could be used to measure other parameters of interest, such as nutrient content and contaminants such as PFAS.

Table 9: Group 2 plastic pollution prioritized indicator and monitoring methods

What?	Plastic pollution
Why?	● Food safety (end uses) ● Social licence

How?	● Beach surveys
	● Microplastics:
	    ○ Plankton trawls: filter water samples or look for floats
	    ○ Sediment samples (microscope, look for fibres)
	● Waste management plans:
	    ○ Inventories of gear each day to look for and document losses
	    ○ Marking gear - marking floats or adopting a system of colour-coded ropes by activity as in US fisheries)
	    ○ US mandates a certain rope colour for specific fisheries to better track contributions from each sector (e.g., NOAA guidelines for East coast of US lobster fishery) (He and Suuronen 2018)
	● Alternative materials:
	    ○ Wool
	    ○ Hemp
	    ○ Carbon fibre rods ('breakaway' properties)
	    ○ Seaweed fibres for ropes
	    ○ Cost barrier here for farmers in adoption of higher-end materials
	● Note: Could be contentious for farmers, as attribution of plastic pollution to the farm itself can be challenging

Who?	● Farmers could be looking at water samples / filtering ● Limited regional capacity → Canadian Food Agency ● Degrading spool lines, if not main ropes. Potential for incentives and subsidies

Table 10: Group 2 bioaccumulation prioritized indicator and monitoring methods

What?	Bioaccumulation
Why?	● Farmers want to know about the quality of their product ● Could affect suitability for end uses / markets ● Food safety / quality

How?	● Sending samples to labs
	● Accumulation can change over the course of the season, and vary in different parts of the stipe and frond
	● Can be expensive (though less than sediment samples)
	    ○ Depends on scale of operation and how lucrative the end market is (e.g., biostimulants may be more worth it)
	    ○ Also depends on the contaminant (e.g., can be up to $1-2k to process samples for some contaminants)
	● Can look at heavy metals, PFAS, nutritional profiles

Who?	● Farmers can sample and send tissue samples to lab

	• Site selection (pre-choice, or moving next season)

Bottom sediment

Monitoring sediments below farms was seen as important for detecting ecosystem change more broadly. During discussions, participants often mentioned sediment sampling as a monitoring method for other indicators, including carbon storage, nutrient availability, and pollution. However, only Group 1 chose to focus on bottom sediments as a prioritized indicator (Table 11). They discussed methods such as day grabs (which can be quite expensive), seabed sonar, and sediment size analysis (which requires specialized equipment). Overall, participants felt that bottom sediment is an important indicator for monitoring, but the high cost and complexity of doing so prohibits it from being a realistic core indicator at every farm. However, it could be a good candidate for researchers or government agencies to study at a few sentinel sites.

Table 11: Group 2 bottom sediment prioritized indicator and monitoring methods

What?	Bottom sediment
Why?	• Informing site selection

How?	• Standard operating procedures (SOPs) enacted by environmental consultants in soft sediment
	• Day grabs in soft sediment/rocky areas
	• Sonar to know whether grab samples are possible (expensive)
	• Note: this equipment often needs to be hired out
	• Tracking longer range impacts
	    ○ Might not see any effects with seasonal farms
	    ○ UK work has not shown additional impacts of seaweed farms on sediment

Who?	• External support system; deploy people to sites to do monitoring • DFO Coastal Baseline Monitoring Program ○ However, in-region capacity is limited • Taxonomists needed to identify invertebrates

Plenary

During the plenary session, breakout facilitators summarised the discussions held in their respective rooms and then turned it over to participants for input via a series of Mentimeter poll questions, summarised below.

How can we monitor cumulative effects of multiple farms?

Participants noted the importance of:

- Collaboration and coordination
- Co-governance and co-monitoring agreements
- Learning from other regions
- Leveraging existing wild kelp monitoring initiatives
- Using standardized, cost-effective monitoring tools in the field alongside modelling methods

- Drawing upon Indigenous knowledge
- Improving data on farm size

How can we improve uptake of monitoring?

Participants shared that monitoring could be added as a condition of licensing, with incentives and grants to reduce its financial burden. Indicators should include both negative and positive effects, including those that are intrinsically beneficial for farmers to measure. Investment in local monitoring, indicator co-creation, and strong science communication are important for improving monitoring buy-in. As farms grow, monitoring technologies change, and governance systems evolve, ensuring that monitoring is coordinated, adaptable, and transparent will be more crucial than ever.

What emerging trends could have implications for monitoring?

Participants highlighted several emerging trends that could have implications for seaweed farming monitoring, including:

- New technologies (e.g., artificial intelligence, satellite remote sensing, drones)
- Budget constraints
- Changing governance and policy (e.g., strengthened First Nations / Tribal oversight, biodiversity credit systems, new aquaculture policies, open-net salmon farming moratorium in BC)
- Integrated multi-trophic aquaculture
- Climate change
- Emerging seaweed end-uses (e.g., bioplastics)

Conclusion & Next Steps

In their reflections on the workshop, participants expressed the importance of collaboration and sharing experiences, coordinating research efforts, standardising monitoring methods, and drawing upon Indigenous knowledge and input. When thinking through indicators, some participants shared the feeling that they needed to choose between 1) indicators that were more easily measurable and easy to communicate, and 2) those that were seen as more pressing but difficult to measure. In addition, farm size needs to be discussed more as it relates to farm effects and regulatory size limits so that it can subsequently be worked into policy. While challenges such as differing regulatory environments, the need for consistent data, and a lack of support for conducting monitoring at scale exist, participants noted that there are many monitoring projects already underway. Moreover, they expressed that workshops such as these provide a powerful opportunity to strengthen coordination efforts and inform policy.

Next steps for this project include conducting interviews and performing a thorough literature review to finalize recommended monitoring indicators. Findings will be shared publicly in early 2026 as part of a Monitoring Framework Report and an accompanying public presentation.

References

Bates, C., McIntosh, D., Rimmer, T., Pedde, D., Clark, J., Macfarlane, G., Anaka, R., Albu, A. B., & Juanes, F. (n.d.). Cameras, Computers, and Collaboration: Cutting Edge Approaches to Marine Fish Monitoring. Fisheries, n/a(n/a). https://doi.org/10.1002/fsh.11104

Bemmels, J.B., Starko, S., Weigel, B.L., Hirabayashi, K., Pinch, A., Elphinstone, C., Dethier, M.N., Rieseberg, L.H., Page, J.E., Neufeld, C.J. and Owens, G.L., 2025. Population genomics reveals strong impacts of genetic drift without purging and guides conservation of bull and giant kelp. Current Biology.

Byron, C.J., Koch, S.J., Callier, M.D., Kluger, L., Angel, D.L., Vanaverbeke, J. and Filgueira, R., 2024. Indicators for ecological carrying capacity of bivalve and seaweed aquaculture. Reviews in Aquaculture, 16(4), pp.2010-2022.

Clark, D., Newcombe, E., Clement, D., Magnusson, M., Lawton, R., Glasson, C., & Adams, S. (2021). Stocktake and characterisation of Aotearoa New Zealand's seaweed sector: Environmental effects of seaweed wild-harvest and aquaculture (Report for Sustainable Seas National Science Challenge Project Building a Seaweed Sector: Developing a Seaweed Sector Framework for Aotearoa New Zealand. (Project Code 2.5)).

Druehl, L., & Clarkston, B., 2016. Pacific Seaweeds: Updated and Expanded Edition (2nd ed.). Harbour Publishing.

Eger, A. M., Bauer-Civeillo, A., Bernal, B., Bohachyk, S., Janke, D., Arroyo, N. L., Schreider, M., & Earp, H. S, 2024. Monitoring Kelp Forest Ecosystems A Guidebook to Quantifying Biodiversity, Ecosystem Health, and Ecosystem Benefits. Kelp Forest Alliance, Ocean Wise.

Gierke, L., Coelho, N.C., Khangaonkar, T., Mumford, T. and Alberto, F., 2023. Range wide genetic differentiation in the bull kelp Nereocystis luetkeana with a seascape genetic focus on the Salish Sea. Frontiers in Marine Science, 10, p.1275905.

Good, M., C. Sannito, and L. Meyer, 2021. Seaweed Handling and Processing Guidelines for Alaska. Alaska Sea Grant, University of AlaskaFairbanks. Fairbanks, Alaska. https://doi.org/10.4027/shpga.2021

Grant, W.S. and Chenoweth, E., 2021. Phylogeography of sugar kelp: Northern ice‐age refugia in the Gulf of Alaska. Ecology and Evolution, 11(9), pp.4670-4687.

Gruenthal, K. M., and C. Habicht. 2022. Literature review for implementation of the 50-50 rule for cultivation of seaweeds and other aquatic plants in Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 2A22-01, Anchorage.

Gutzmann, S.B., 2023. Centering Indigenous governance principles, values, and objectives to build a just blue economy decision space. MRM, Simon Fraser University

Gutzmann, S.B., & Cisneros-Montemayor, A.M., in prep. Planning for an expanding industry: Opportunities for a successful kelp economy in British Columbia. [Manuscript in preparation.]

Hansen, T., 2023. Native Voices | Traditional uses for seaweed. The Cordova Times. https://thecordovatimes.com/2023/12/13/native-voices-traditional-uses-for-seaweed/

He, P. and Suuronen, P., 2018. Technologies for the marking of fishing gear to identify gear components entangled on marine animals and to reduce abandoned, lost or otherwise discarded fishing gear. Marine Pollution Bulletin, 129(1), pp.253-261.

Jones, M., 2023. Where Can We Grow Kelp? Evaluating Data for the Selection of N. Luetkeana Seaforestation and Aquaculture Sites in British Columbia Nearshore Waters [M.S., Royal Roads University (Canada)]. https://www.proquest.com/docview/2828283372/abstract/B7B7471FA4264A18PQ/1

LGL Limited, 2024. RDMW Seaweed Industry Development Plan 2024. Regional District of Mount Waddington.

Martone, R., Gregr, I.R. and Gregr E.J., 2025. Seaweed aquaculture in British Columbia: Policy, regulations, and recommendations for mitigating potential ecological effects. Report prepared for the David Suzuki Foundation by SciTech Environmental Consulting. 2025. 35 pp.

Pawluk, K. and Outhwaite, J. "CARTI Seaweed Series: Q&A with the Province of BC about Kelp Aquaculture and Harvest." *YouTube,* uploaded by North Island College, 15 February 2024, https://www.youtube.com/watch?v=C0n_FyK4Y3c.

Province of BC, 2024. BC Coastal Marine Strategy. Accessed from: https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/coastal-marine-strategy/coastal_marine_strategy.pdf

Stewart H., 1977. Indian Fishing : Early Methods on the Northwest Coast. Douglas & McIntyre

[TNC] The Nature Conservancy, 2024. A global monitoring, evaluation and learning framework for regenerative and restorative aquaculture: Helping nature thrive through aquaculture. Arlington, Virginia, USA

Ward, G.M., Kambey, C.S., Faisan Jr, J.P., Tan, P.L., Daumich, C.C., Matoju, I., Stentiford, G.D., Bass, D., Lim, P.E., Brodie, J. and Poong, S.W., 2022. Ice‐Ice disease: an environmentally and microbiologically driven syndrome in tropical seaweed aquaculture. Reviews in Aquaculture, 14(1), pp.414-439.

Appendix A: Participant List

The following people participated in this workshop and are gratefully acknowledged for their contributions to these findings (alphabetical by first name).

1. Alyssa Allchurch (Simon Fraser University)
2. Amanda Swinimer (Dakini Tidal Wilds)
3. Carol Amaratunga (Cartis Research Inc.)
4. Colin Bates (Cascadia Seaweed)
5. Contina Bechmann (University Marseille Provence)
6. Danielle Denley (BC provincial government)
7. Edward Gregr (Scitech Environmental Consulting)
8. Erin Latham (Wei Wai Kum First Nation)
9. Ian Chan (BC Centre for Agritech Innovation)
10. Isabel Gregr (University of Victoria)
11. Job Cohen (NIOZ Royal Netherlands Institute for Sea Research)
12. Jung Suk Lee (NEB Co.)
13. Karla Colderon (Pakucha)
14. Kiara (Hooi) Choi (Imbada)
15. Kylee Pawluk (BC provincial government)
16. Lila Hobbs (The Pew Charitable Trusts)
17. Lyndsay Silvestre (aquaculture)
18. Lynn Lee (University of Victoria)
19. Mairead Norton (Nanwakolas Council)
20. Mary Williams (Ecotrust Canada)
21. Masa Tatsumi (Sea Forest)
22. Mizuho Namba (Nippon Steel Corp.)
23. Noah Mayor (Central Council Tlingit and Haida Indian Tribes of Alaska)
24. Rafael Cuevas (Cal Poly Humboldt)
25. Sophie Corrigan (Natural History Museum, London)
26. Tamsen Peeples (University of Alaska Fairbanks)
27. Tanya Brown (independent, based in Powell River and working with Vital Kelp)
28. Taylor Beyea (LGL Ecological Research Associates)
29. Tom Rudolph (The Pew Charitable Trusts)
30. Troy Moth (Metlakatla Development Corporation)
31. Vaeno Vigulu (Solomon Islands National University)
32. Varrick Grimes (Kalup)
33. Wendy Lee (Highline Community College)
34. Whee jae Ki (Imbada)

Appendix B: Indicators List

We have categorized indicators by indicator class, largely so that workshop discussions can be broken up into groups (by indicator class). Note that some indicators could be placed into multiple indicator classes. The cumulative effects category is itself cross-cutting, but we have chosen to place indicators inside these limited bins for presentation and workshop purposes.

Indicator Class	Indicator	Example metric(s)
Biological parameters: Habitat use, biodiversity, & biological health	Epibiotia (living on the kelp)	Species identification
		Species abundance
		Species diversity
	Biofouling	Species identification
		% coverage
	Phytoplankton/Zooplankton	Species identification
		Species abundance
		Species diversity

Indicator Class	Indicator	Example metric(s)
	Harmful algal bloom (HAB) risk	Event incidence
		Event severity
	Fish	Species identification
		Species abundance
		Species diversity
	Benthic (bottom)	Species identification
		Species abundance
		Species diversity
		Dispersal from farm
	Bird	Species identification
		Species abundance
		Species diversity
	Mammal	Species identification
		Species abundance
		Species diversity
	Entanglement Risk	Bird entanglement
		Mammal entanglement
	Habitat enhancement	Refugia usage
		Structural diversity
	Habitat disturbance	Monitoring frequency
		Farm maintenance frequency
	Genetic diversity	Farmed vs. wild kelp
	Disease risk (within species)	Infection rates
		Transmission rates
	Disease risk (between species)	Infection rates
		Transmission rates
	Invasive species risk	Distribution
		Abundance
Abiotic parameters: Water and sediment	Nutrient provision & carbon storage	Nitrogen and phosphorous assimilated and extracted with farmed biomass
		Trends in kelp nutritional content (% C, % N, C:N)
		Nitrogen (NO_3 and NH_4) concentrations around farm
		Dissolved inorganic nutrients (nitrate, nitrogen dioxide, ammonium, phosphate, silicon dioxide)
		Dissolved oxygen in water column at farm site
		Seaweed nutritional content (% C, % N, C:N)
		Chlorophyll a concentrations in water column
		Fatty acid profiles of seaweed grazers
		Detritus sinking rates
		Particulate organic matter (POM)
		Dissolved organic matter (DOM)
		Annual tonnes CO_2 sequestered and retained in farmed biomass (e.g., tonnes C / ha, t CO2 / ha)
		CO_2 influx
		Carbon capture rates (g C / m^2 per day), estimated from net ecosystem productivity
		Erosion of standing kelp biomass
		Sediment organic carbon content
	Flow	Lateral / vertical flow velocity
		Lateral / vertical flow diffusivity

Indicator Class	Indicator	Example metric(s)
		Flow velocity deficit
		Turbulent kinetic energy (TKE)
		Mixed layer depth
	Sediment composition	Deposition of seaweed fragments
		Sediment composition and grain size
	Light penetration	*Turbidity:* Suspended sediment concentration (SSC)
		Turbidity and shading: Light intensity (PAR, measured in micromoles per square meter per second)
		Turbidity and shading: Light intensity - overall brightness (lux, measured in lumens per square m)
	Wave energy	% change in wave energy flux
		Wave decay coefficients
	Acidification	pH
		Alkalinity (buffering capacity)
		Partial pressure of carbon dioxide (pCO2) in seawater
		Dissolved inorganic carbon (DIC)
		Aragonite saturation state
		Calcite saturation state
		Acidification potential
	Temperature	SST (degrees C)
	Salinity	Salinity (ppt)
Pollution parameters*: Water, air, sediment, biota **Note that nutrients may also be considered a pollutant, but are addressed under Abiotic Parameters*	Aqueous chemical pollutants	Concentrations in water (e.g., ng/L)
		Concentrations in seaweed (e.g., ug/kg ww)
	Microplastics	Concentrations in water(e.g., items/g)
		Concentrations in biota (e.g., items/individual)
	Sewage	Chemical profile
		Biochem/chemical oxygen demand
		Total suspended solids
	Bioaccumulation & biomagnification	Bioaccumulation factor (BAF)
		Bioconcentration factor (BCF)
		Trophic transfer factor (TTF)
		Biomagnification factor (BMF)
	Noise	Decibels in water or air
		Sound sources
	Airborne pollutants	Vessel emissions
		Portable engine emissions
Cumulative effects	Farm level	Total seaweed biomass
		Total farm area
		Total farm nutrient flux
		Alpha diversity (biodiversity within a single community/ecosystem)
	Between farms	Beta diversity (difference in species composition between different communities/ecosystems)
	Across farms	Gamma diversity (total diversity across landscape or region)