Seaweed aquaculture in British Columbia: Policy, regulations, and recommendations for mitigating potential ecological effects

Prepared for the David Suzuki Foundation
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EXECUTIVE SUMMARY

This report examines the ecological effects and regulatory frameworks relevant to seaweed aquaculture in British Columbia. Combining information from available literature, extra-jurisdictional practice and expert interviews with aquaculture regulators, seaweed growers and ecologists, we summarize B.C.'s existing seaweed aquaculture operations and management, and the potential ecological interactions that may result from seaweed aquaculture expansion.

Our analysis of the literature reveals evidence for positive and negative ecological effects of seaweed aquaculture. The potential negative effects, such as competition for light and nutrients, disruption of local food webs and risks associated with large-scale operations like deep-water sinking for carbon sequestration, highlight the need for careful management. These findings are corroborated and contextualized through interviews with ecologists, growers and regulators from the Pacific Northwest and eastern Canada. They underscore the importance of site-specific approaches and adaptive policies to balance benefits and risks.

The current regulatory framework in B.C. involves several provincial and federal agencies with different jurisdictions, including the B.C. Ministry of Water, Land and Resource Stewardship, B.C. Ministry of Agriculture, Fisheries and Oceans Canada and Transport Canada. Each agency applies regulations and policy stemming from its own enabling legislation. Only the B.C. Fish and Seafood Licensing Regulation directly addresses the cultivation of aquatic plants, but it is limited in scope and does not address cultivation for non-human consumption. This highlights the need for updated and specific legislation and streamlined governance to address specific ecological and operational concerns.

Recognizing the complexity of regulatory change, we emphasize the importance of transparency and broad stakeholder engagement and highlights the challenges of jurisdictional gaps and ministerial discretion. We provide general recommendations, with an understanding that policies (which are more flexible and faster to adapt than regulation) can offer immediate guidance. Recommendations include addressing the offshore jurisdictional gap, full consultation with First Nations and across all levels of government, and a robust and updated seaweed aquaculture-specific policy. This will ensure transparency, protect the health of wild and farmed seaweeds in a changing ocean and provide clear and comprehensive guidance for growers and managers.

BOX 1 :
KEY FINDINGS

Ecological effects

Seaweed aquaculture comes with a range of potential ecological effects. Some may have positive outcomes for marine ecosystems and species and others may lead to negative outcomes. Potential positive effects include the inhibition of harmful microalgae blooms, reduced eutrophication and increased buffering against ocean acidification. Increased primary production, habitat provisioning, carbon sequestration and shoreline protection may also occur, although there is generally less evidence for these benefits in an aquaculture context.

Of the potential negative consequences, the most significant may include genetic disruption of wild seaweeds, and the introduction of species, pathogens or disease to local ecosystems. While these may be of potentially high consequence, their likelihood is unknown. Other potential negative effects include competition with other primary producers for nutrients and sunlight, and effects on the seafloor, including localized anoxic zones. Entanglement with marine mammals is a consideration whenever lines are used in marine ecosystems, but the likelihood is relatively low for seaweed aquaculture in B.C.

These and other effects will be influenced by decisions regarding farm site selection, farm size, seed stock sourcing, crop density, harvest timing, nursery practices and marine debris management.

Regulation and management

Jurisdictional gaps and a lack of legislation specific to seaweed aquaculture are key sources of uncertainty.

The relevant regulatory framework involves four provincial and federal agencies with different jurisdictions: in the province, the B.C. Ministry of Water, Land and Resource Stewardship and the Ministry of Agriculture, and federally, Fisheries and Oceans Canada and Transport Canada.

Each agency applies regulations and policy stemming from its own enabling legislation. However, specific legislation for the cultivation of aquatic plants is limited. For example, the British Columbia Fish and Seafood Act does not apply to aquaculture products that are not for human consumption. Farms growing products for other uses are only issued a tenure under the Land Act, and do not require a licence under the Fish and Seafood Act.

While these agencies work together in a harmonized process to review proposals and create conditions of licence, key gaps remain.

Specifically, there is a critical gap in understanding which agencies would have jurisdiction over seaweed aquaculture in offshore areas (i.e., more than 12 nautical miles offshore). While there are no seaweed aquaculture operations currently located in Canada's offshore waters extensive offshore seaweed aquaculture has been proposed as a potential climate change mitigation strategy at the global scale.

Multiple jurisdictions and the lack of specific legislation and regulations result in mitigation measures that are primarily based on best practices identified by the provincial and federal project review team. These mitigation measures are then included in conditions of licence and farm management plans.

BOX 2 :
KEY RECOMMENDATIONS

Our primary recommendation is for a comprehensive conversation with First Nations communities and governments to understand First Nations perspectives on governance and social, cultural, economic and ecological issues of the seaweed aquaculture industry, in the context of the Declaration on the Rights of Indigenous Peoples Act.

We also recommend a more comprehensive approach be developed through collaboration between all levels of government to review the potential ecological effects of this emerging industry, particularly with respect to coastal communities, and the relevant governance structures addressed.

The potential ecological effects of seaweed aquaculture, legislative complexity, and jurisdictional gaps highlight the need for updated and specific legislation and streamlined governance to address ecological and operational concerns.

The offshore jurisdictional gap is a specific issue that requires legislative clarity. Since provincial jurisdiction ends 12 nautical miles from the outer coast, no B.C. legislation applies beyond this limit.

Updating the B.C. Fish and Seafood Act and Fish and Seafood Regulations would help clarify and strengthen protections for the nearshore marine environment.

In the near term, policy should be developed to offer immediate guidance. Policies are flexible and faster to adapt than regulation. As the current Land Use Aquaculture Policy overlooks seaweed cultivation, the current effort by B.C. to release a seaweed aquaculture policy by the end of 2025 is welcome news. The policy will draw on recommendations from the B.C. Coastal Marine Strategy, which was co-developed with coastal First Nations, to inform the updated seaweed aquaculture policy and increase clarity and transparency.

Throughout these engagements, we emphasize the importance of transparency and balance in stakeholder engagement.

BOX 3 :
WHAT THIS REPORT DOESN'T COVER

In this report we limited our focus to the ecological effects of seaweed farms in B.C. We did not address the cultural and social relationships between the Indigenous people of the eastern North Pacific and their coastal ecosystems, as a comprehensive accounting is beyond the scope of this effort. However, we recognize that all things are connected, and acknowledge that focusing solely on "ecological" effects is reductionist.

As Indigenous people have been tending and harvesting seaweeds in this region for millennia (Turner 2020, Reid et al. 2022), it is not possible to fully separate what is "ecological" from what is "social and cultural," thus the former cannot be assumed to exist in its current state without the latter. We acknowledge the social and cultural services provided by seaweeds and recognize the need to address these critical aspects of seaweed cultivation, along with other aspects of governance. We suggest this would be best done by coming together in a broader, inclusive forum (see Recommendations).

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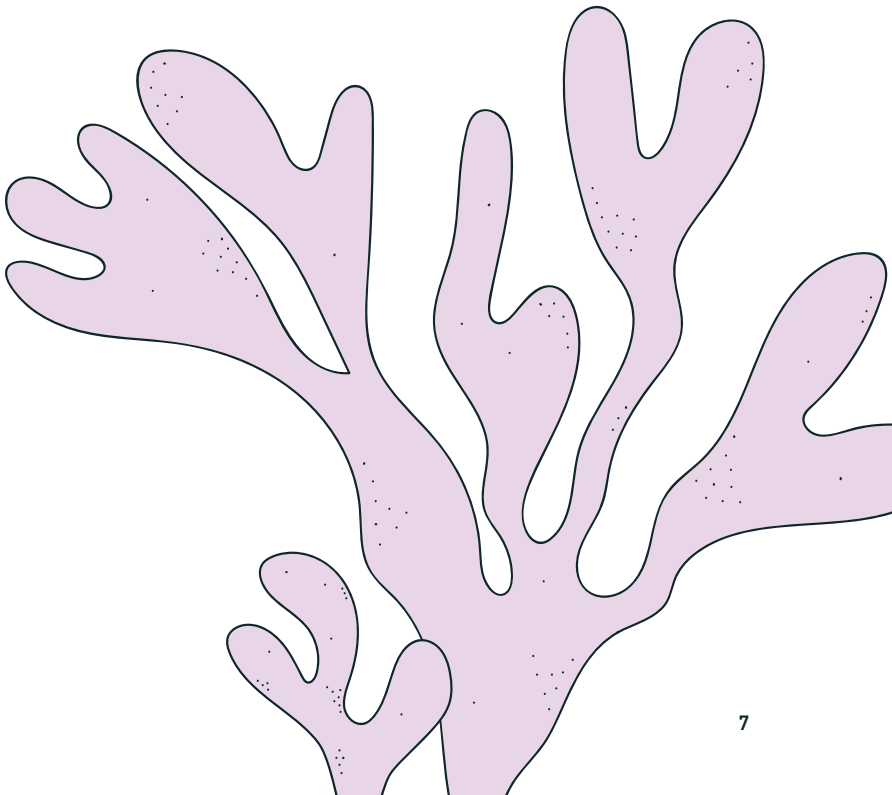


INTRODUCTION

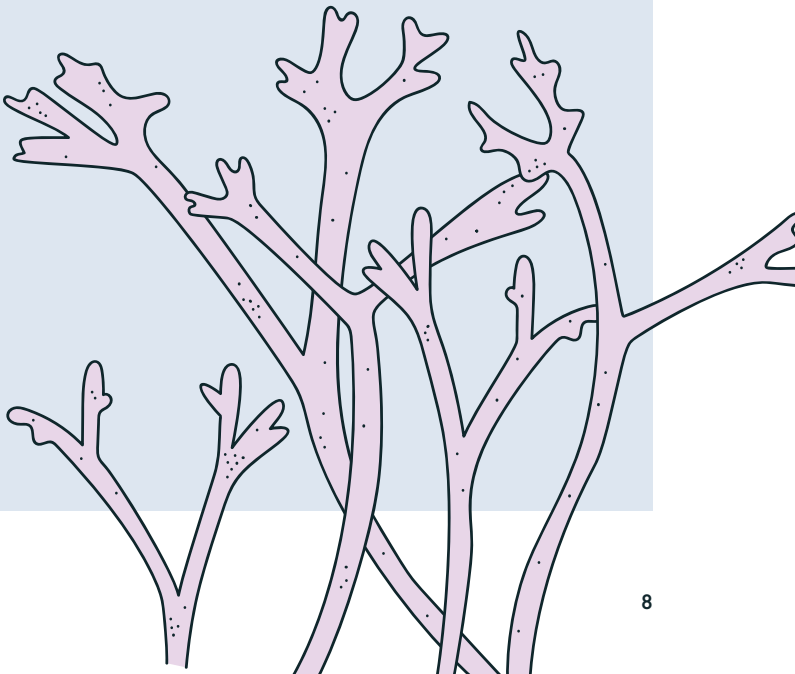
The potential benefits associated with seaweed aquaculture, particularly kelp species (Alleway et al. 2023a), has contributed to increased interest in aquaculture efforts in the eastern North Pacific. Seaweed aquaculture is developing rapidly in this region, which includes southeast Alaska, British Columbia, Washington and Oregon. Canada has been identified as one of the world's most promising regions for seaweed aquaculture expansion (Alleway et al. 2022), and with a coastline length of over 25,000 km, B.C. has considerable potential for development (Alleway et al. 2023a).

However, as with any emerging industry, many questions remain about its sustainability. Given the myriad ways industrial seaweed aquaculture may influence coastal ecosystems, development of a sustainable seaweed aquaculture industry must be accompanied by a robust, transparent regulatory regime. In this report, we focus on how seaweed aquaculture is currently managed in B.C., whether the current regulatory and policy regime addresses the many ways seaweed aquaculture is likely to affect coastal ecosystems and how the regulatory regime could be improved to ensure ecological sustainability.

BOX 4: WHY IS INTEREST IN SEAWEED EXPANDING?

Aquatic vegetation, including mangroves, grasses and seaweeds (specifically kelps), are critical components of coastal ecosystems (Duarte et al. 2005, Macreadie et al. 2017). Despite vegetated coastal ecosystems being restricted to a thin band along the coast, these habitats contribute one to 10 percent of global marine net primary productivity (Duarte et al. 2017). Aquatic vegetation also supports global fisheries by providing food, shelter, predator protection and nursery grounds to many valued species (Macreadie et al. 2017). These ecosystems are also increasingly understood to be integral to the marine carbon cycle through their capacity to store and sequester carbon (Siikamäki et al. 2013). As such, they have the potential to aid in carbon drawdown by capturing greenhouse gases and sequestering carbon for long durations (Macreadie et al., 2021). In temperate latitudes such as the west coast of North America, dominant aquatic vegetation include grasses and seaweeds, particularly kelp (Chambers et al. 1999, Sherman and DeBruyckere 2018).

Depending on farming practices, cultivated seaweeds can offer some of the ecological benefits associated with natural seaweed beds, and can also be processed into a range of products and uses with broader environmental and social benefits. These include new low-carbon products such as seaweed-based textiles, antimicrobial bandages, biofuels and biodegradable plastic alternatives (Lang-Wong 2022). Seaweeds are also being cultivated to provide methane-reducing feedstocks for cattle and other ruminants, as well as organic fertilizers intended to mitigate climate change (Yong et al. 2022).



METHODS

Drawing on the available literature, extra-jurisdictional practice and interviews with experts across the eastern North Pacific, we set the global context for seaweed aquaculture and review B.C.'s existing seaweed aquaculture operations, with a focus on currently cultivated species. We then summarize the range of ecological effects that may arise from a developed seaweed aquaculture industry. We identify those that are most likely to occur in B.C., and the potential severity of any impact.

Throughout, we considered the likelihood of occurrence separately from the severity, as the question of risk must consider both dimensions. For example, marine mammal entanglements could have significant consequences, but the evidence suggests the likelihood is low. This would typically lead to a low risk assessment unless the species is endangered. Given the necessary value judgment in assessing risk, we limit our discussion to the likelihood and severity of impacts, unless risk was explicitly (and correctly) used in the literature or by our interviewees.

We reviewed relevant literature using a citation-chaining approach, starting with a collection of recent overview papers describing the positive and negative effects of seaweed aquaculture. We included global research but also aimed for papers, websites and gray literature that focused on temperate seaweed aquaculture relevant to the eastern North Pacific. The literature review formed the foundation for our interviews with regional seaweed aquaculture experts.

We identified our experts based on their knowledge of the seaweed aquaculture industry, short-listing both regional ecologists and regulatory authorities. We pared the list based on individual availability, while ensuring a cross-section of expertise from different regions. We also considered additional interviewees recommended by our initial list of experts. We used semi-structured interviews with questions tailored to specific areas of expertise (e.g., regulation, farming and ecology. Questions were grouped into three categories: seaweed cultivation, seaweed aquaculture management and ecological effects.

From 25 experts identified, we held 10 one-hour interviews with followups as needed for clarification. Our interviewees included four industry experts, three ecologists and three regulators. For clarity, any uncited assertions in this report represent the summarized opinions of the interviewees or the authors, based on our interpretation of the responses.

Using this information, we examined the existing regulatory regime and assessed the degree to which potential negative ecological effects are addressed. Finally, we developed recommendations on how B.C. could update the current management approach based on the latest ecological understanding.

THE CURRENT STATE OF SEAWEED AQUACULTURE

GLOBAL CONTEXT

According to the United Nations Food and Agriculture Organisation (FAO), global seaweed output (both aquaculture and wild) has increased nearly threefold from 118,000 tons to 358,200 tons from 2000-2019 (Stankus 2021) and the sector continues to grow and innovate. Currently, global production is dominated by producers in Asian countries, with only 1.36 per cent coming from the Americas and 0.04 per cent from Canada (Zhang et al. 2022).

As of 2019, five key seaweed types accounted for over 95 per cent of global seaweed production. These include *Laminaria* and *Saccharina, Kappaphycus* and *Eucheuma*, *Gracilaria*, *Porphyra* and *Undaria* (Zhang et al., 2022). Most seaweed aquaculture is done using mariculture although some land-based farming occurs (Zhang et al., 2022, Garcia-Poza et al., 2020). For land-based farming, seaweed is mainly grown in closed systems, such as water tanks, lagoons and ponds (García-Poza et al. 2020, Zhang et al. 2022). The land-based approach is applicable for many seaweed species as it is relatively straightforward and allows for real-time monitoring and effective control of culture conditions (Zhang et al., 2022). However, land-based aquaculture requires higher maintenance and can be limited by land scarcity (Zhang et al., 2022). In contrast, mariculture can cover larger areas and requires less maintenance (Zhang et al., 2022). Shallow-water mariculture, with fixed piles installed in the bottom from depths of five to 50 metres (Yahya et al. 2020, Zhang et al. 2022), is currently the most common method of seaweed aquaculture. Increasingly, farms are employing floating rafts or long ropes to create rafts of algae (Yahya et al. 2020, Zhang et al. 2022). This is the approach used in the eastern North Pacific, presumably because of the predominantly rocky coastline.

BRITISH COLUMBIA AND THE PACIFIC NORTHWEST

Environmental conditions in B.C. allow for seaweed aquaculture on land, in the nearshore and offshore. We define nearshore aquaculture as anchored facilities in sheltered coastal waters typically shallower than 40 metres. Offshore farms in deeper, more exposed waters distant from shore have been envisioned (e.g., National Academies of Sciences 2021) but would require more extensive infrastructure and anchoring systems, and thus would need to be much larger to be economically feasible. Beyond that, some are envisioning floating, untethered seaweed aquaculture beyond the continental shelf, specifically for abyssal carbon sequestration (Ross et al. 2022). We consider the ecological and regulatory landscape for each of these contexts.

The B.C. *Fish and Seafood Act* (FSA) lists 33 taxa of aquatic plants organized into eight groups based on morphology and life history characteristics and a ninth group that is meant to represent any other non-listed species (Appendix 1). These are identified in relation to wild harvest but are also relevant for seaweed aquaculture. The primary species cultivated in B.C. are naturally occurring in local waters and include *Saccharina latissima* (sugar kelp), *Alaria marginata* (winged-kelp) and *Macrocystis tenuifolia* (giant kelp, recently reclassified from *pyrifera* as it is genetically distinct from the South American form (Lindstrom 2023)). These species are typically cultivated on anchored longlines in about three metres of water at depths from 10 to 30 metres over soft sediments.

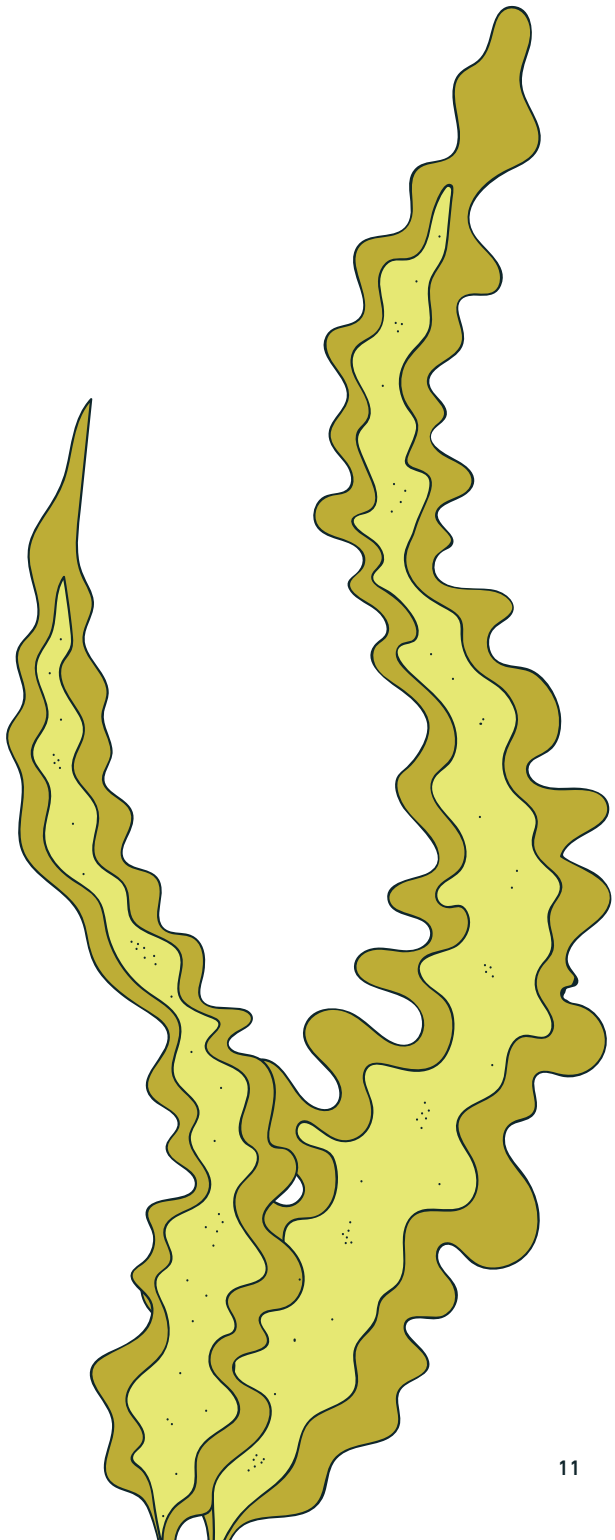
Currently, the maximum depth of farms is typically 40 metres as the costs of anchoring increase in deeper waters. Harvesting begins in the fall when wild kelp trimmings are collected, and their spores are then spread on twine (Jones 2023). To reduce the possibility of genetic mixing, the province currently only approves permits where seaweed spores are sourced within a 50-kilometre radius of the farm

(Jones 2023). After about a month, the twine is transferred to the ocean farms, where it is wrapped around the longlines (Jones, 2023). Growth occurs during the winter months, and by March or April the fronds are ready for harvest (Jones 2023).

Other kelps, such as *Nereocystis luetkeana* (bull kelp), are also farmed by some growers. Lab-grown individuals are outplanted on suspended underwater longlines, and harvested after five months of growth (Seaforest, 2024). Other licensed species include *Condracanthus exasperatus* (Turkish Towel), *Gracilaria* spp., *Agarum* spp. and *Ulva* spp.; however, it should be noted that just because a grower has a licence, it doesn't necessarily mean the species is cultivated. Other species (e.g., *Neoagarum fimbriatum, Cymathere triplicata*) have been tested for cultivation but are not currently grown because of poor market conditions. Finally, other native species of interest for cultivation (e.g., *Pyropia* spp.) are currently not grown because of cultivation challenges. Non-native species are currently prohibited in coastal mariculture under conditions of licence.

Land-based aquaculture in B.C. includes nurseries (to grow out individuals from spores for outplanting), and tanks to grow phytoplankton for food supplements and some seaweeds to maturation. For example, Cascadia Seaweed has a licence to grow *Devaleraea mollis* (Dulse, a red seaweed) in tanks on land. Water for the tanks is sourced from the nearshore, sand-filtered, then passed through five-micron screens, sterilized with UV and returned to the marine environment. Each tank is equipped with temperature control and LED lighting to optimize growth (Government of B.C. 2021). Under conditions of licence, land-based growers must ensure no seaweed gametophytes or sporophytes, or pathogens and parasites are introduced beyond waters where they are naturally found.

As the seaweed aquaculture industry is still new in B.C., production remains low. In 2021, the two largest growers, Cascadia Seaweed and Seaforest, cultivated a total of about 65 hectares across nine farms (Held 2021). As of 2025, Cascadia has 120 ha of tenured space comprised of 30 ha in cultivated area. Smaller operators, including facilities owned and operated by First Nations, are in the development phase, but efficient product delivery and processing remains a key limiting factor for the industry in the eastern North Pacific.



ECOLOGICAL EFFECTS OF SEAWEED FARMS

In B.C. (as in most places), the industry does and will continue to rely on the marine ecosystem to provide seed stock, nutrients and water circulation. Farms are therefore deeply embedded in the coastal ecosystem. As such, there are multiple ways seaweed aquaculture may interact with wild marine ecosystems. Using a pathways-of-effects framing (Government of Canada 2012), we identify the effects attributable to seaweed farming and detail the measurable endpoints resulting from these effects.

Our examination of the literature reveals that there is more evidence to draw on for positive effects than for negative effects. This is partially due to inferences of positive ecological effects that can be drawn from research on wild kelp forests. Additionally, negative ecological effects are more evident in large established farms in shallow, sheltered waters (e.g., Duarte et al. 2023). There are no such operations yet in place in rocky temperate waters.

Positive effects of seaweed farming include fixing of inorganic nutrients (i.e., nitrogen and phosphorous), thereby reducing eutrophication (Duarte et al. 2017, Stephens and Umanzor 2024) and harmful micro-algal blooms (Spillias et al. 2023). It may also create refugia from ocean acidification (Xiao et al. 2021) by drawing down dissolved inorganic carbon. The farms themselves may attract species, provide habitat (Corrigan et al. 2022) and increase primary production (Sato et al. 2022). They may also protect shorelines from the effects of storm surge (Spillias et al. 2023); however, under conditions where water exchange is important, such attenuation may be deleterious (Bhushan et al. 2023). Conversations with experts revealed several benefits not widely discussed in the literature. These include the role of farms in restoration aquaculture through positive spillover effects (e.g., rebuilding seed sources for bull kelp) to support restoration efforts. Noise reduction was also mentioned, suggesting that seaweeds could attenuate underwater sound waves in the same way they contribute to shoreline protection.

However, seaweed aquaculture may also have negative effects for marine ecosystems. For example, competition for nutrients (Campbell et al. 2019, National Academies of Sciences 2021), particularly in more oligotrophic waters, is but one of a range of potential interactions between seaweed aquaculture and plankton that could change local food webs by attracting species or promoting growth. These effects could reach as low on the marine trophic web as viral predation on bacteria (Clasen and Shurin 2015). Competition and habitat change from mariculture could also reduce the productivity of wild seaweeds, phytoplankton and benthic communities. For large farms (>50 hectares), such as those envisioned for atmospheric carbon dioxide removal (see National Academies of Sciences 2021), proposed deep-water sinking of farmed biomass for carbon sequestration could lead to anoxic zones and changes in benthic food webs and water chemistry (National Academies of Sciences 2021). Similarly, the significant deposition of lost biomass below farms (Duarte et al. 2025) may lead to local anoxic conditions.

Furthermore, a host of potential effects may emerge as the industry develops. For example, the potential for biomagnification of microplastics and other contaminants by large-scale seaweed aquaculture has been identified as a potential negative effect (Zhang et al. 2022). Additionally, the history of seaweed cultivation shows how domestication of seaweeds will be unavoidable with a mature industry (Valero et al. 2017). How such cultivars would interact with natural populations is unknown but could include direct competition and genetic disruption (Campbell et al. 2019), through both reduced genetic diversity and crop-to-wild gene flow (Valero et al. 2017).

Other potential risks include entanglements (ICES 2023), nuisance macro-algal blooms (Spillias et al. 2023), species introductions and pathogens and diseases (United Nations Environment Programme 2023). Lost or discarded infrastructure (including anchor systems, ropes and buoys) or farming components during operations and

decommissioning could add to marine pollution and debris if farms are poorly managed (Campbell et al. 2019). Finally, cumulative effects leading to reduced resilience could be a concern for both farmed and wild kelps. However, assessments of cumulative effects of seaweed farming on the biodiversity or resilience of ecosystems have not been conducted to date (Spillias et al. 2023), and would be extremely challenging to conduct.

How seaweed aquaculture will actually affect ecosystems in any given context will depend on the site and the size of the farm (United Nations Environment Programme 2023), as well as factors such as the species farmed, cultivation method, local hydrodynamics, nutrient status of the ecosystem and the ability to effectively manage the aquaculture sector (Alleway et al. 2023b). Furthermore, not all consequences are equally likely to occur, nor are

BOX 5:
TABLE 1: POTENTIAL ECOLOGICAL EFFECTS OF SEAWEED AQUACULTURE IN THE EASTERN NORTH PACIFIC: ENDPOINTS, RISK, AND MITIGATION POTENTIAL

Potential effects of seaweed cultivation in the eastern North Pacific, the strength of evidence, the ecological endpoints and their likelihood of occurrence, consequence and potential for mitigation (all as low, moderate or high). Green indicates potential positive effects on endpoints, red indicates potential negative effects.

EFFECT	EVIDENCE	ENDPOINT	LIKELIHOOD	CONSEQUENCE	MITIGATION POTENTIAL
Fixing of inorganic nutrients	High	Inhibition of bloom-forming microalgae	High	Moderate-High	NA
		Reduced eutrophication	Moderate	Moderate	NA
		Competition for nutrients	Moderate	Data deficient	High
Fixing of dissolved inorganic carbon (DIC)	High	Carbon sequestration	Low	Low	NA
		Reduced ocean acidification	Moderate	Low*	NA
Increased particulate organic carbon (POC)	High	Increased primary production	Moderate	Moderate	NA
		Anoxic zone	Low	Data deficient	High
Species attraction	High	Macro-algal pest blooms	Moderate	Moderate	High
		Habitat provisioning**	Moderate	Data deficient	NA
	Moderate	Species interactions**	Moderate	Data deficient	Moderate
Wave attenuation	Moderate	Shoreline protection	Low	Low	NA
	Low	Reduced noise pollution	Low	Low	NA
Shading	High	Competition for light	Low	Data deficient	High
Benthic deposition of POC	High	Altered benthos** (nearshore)	Low to Moderate	Data deficient	Moderate
		Altered benthos** (offshore)	Data deficient	Data deficient	Moderate
Cultivation	Moderate	Genetic disruption	Data deficient	High	High
		Species introductions	Data deficient	High	Moderate
		Pathogens and disease	Data deficient	High	Moderate
	Low	Habitat alteration**	Data deficient	Moderate	Moderate
Material interactions	Low-Moderate	Entanglements of megafauna	Low	High	Moderate
		Marine pollution	Low	Low*	High
		Marine debris	Low	Low*	High

* Although local effects could be high. ** These endpoints may also alter species distributions, and local biodiversity.

they equally understood. Despite this diversity of potential ecological effects, recent reviews have suggested the greatest risks are likely to be from nutrient depletion, introduction of disease and pathogens and invasive species, genetic disruption and entanglement (Campbell et al. 2019), along with local physicochemical changes (Bhushan et al. 2023).

THE EASTERN NORTH PACIFIC CONTEXT

Although there is little evidence from B.C. and elsewhere in the eastern North Pacific for the ecological effects of seaweed aquaculture, our discussions with ecologists, growers and regulators led to six potential negative effects being repeatedly mentioned. These included non-native species introductions, genetic disruption, disease and pathogens, benthic shading, entanglements and marine debris. However, concern about most of these effects were related to the size of the industry and the farms themselves, with interviewees agreeing that risks from land-based and small to medium nearshore farms (< 50 hectares) were minimal, as long as reasonable mitigation and regulations were in place.

Disease spillover and genetic pollution are some of the most pressing concerns, as mitigation is expected to be difficult, given the high dispersal of biological material in the ocean (UNEP 2023). Disease and pathogens are of increasing concern as the industry expands. Disease can arise from various factors, including nutrient imbalances and infection by pathogens. Pathogens (e.g., bacteria, fungi, viruses, protists) cause disease by invading tissues and disrupting cellular processes. Diseases impair normal physiological functions, often manifesting as visible symptoms like discoloration, tissue necrosis or stunted growth. Stressed plants are more susceptible. The risk is magnified in an aquaculture setting by the reduced genetic diversity, making crops more susceptible to abiotic stressors, disease and parasites (Campbell et al. 2019). Symptoms of environmental stress and disease are more likely to occur in large high-density farms (Vairappan et al. 2007, Edwards and Connell 2012) not anticipated in the eastern North Pacific. Nevertheless, diseased cultivated stands will experience reduced yield and may serve as a disease reservoir that could impact natural populations (Valero et al. 2017). However, very little is known about seaweed disease and pathogens in the eastern North Pacific, and about algae diseases in general. A recent workshop was convened in Alaska (Sealaska Heritage Institute 2023) to address concerns about an emerging pathogen observed in Alaska wild seaweed populations, with intent to develop more knowledge in this area.

Currently only wild-harvested plants are permitted for aquaculture in the eastern North Pacific. However, increasing evidence for adaptation to local conditions suggests that domestication may significantly improve production rates. The effects of genetic disruption, whether through selective breeding on the use of non-local stocks, could be high if poorly managed. Avoiding the release of reproductive material from seaweed farms may be difficult, particularly as the industry expands. The interaction of selectively bred native species with wild populations may lead to loss of genetic diversity (Buckner et al. 2024). However, little is known about the likelihood or consequence of this interaction.

Entanglements and marine debris are not unique to seaweed aquaculture as they have been a consideration in commercial fisheries and shellfish and finfish aquaculture for decades. Expert opinion matched our literature results in that no entanglements in mariculture infrastructure have ever been reported. In contrast, some interviewees expressed concern about the potential negative impacts of acoustic deterrence devices on marine mammals. Several interviewees also confirmed that taut lines and localized infrastructure close to shore make the likelihood of entanglement low, especially when compared to existing industries, particularly commercial trap fishing. The likelihood may increase as the size, location and operational window of farms expands, thus the role of larger, offshore farms warrants more research. However, regulatory concern may be outsized with respect to the actual risk.

Marine debris from nearshore farms was seen as similarly low risk. With hatcheries on floating barges, in boats and shipping containers, the likelihood of debris entering the coastal zone is inevitable;

however, several interviewees suggest that such debris is unlikely to have substantial ecological effects. Further, such pollution is considered to be no worse than that of existing aquaculture operations, with lower consequences than lost fisheries gear or finfish aquaculture sites. However, there was high uncertainty about the effects of large offshore farms, which were identified as having a high potential for debris and pollution given their size and the vulnerability to destruction during storms.

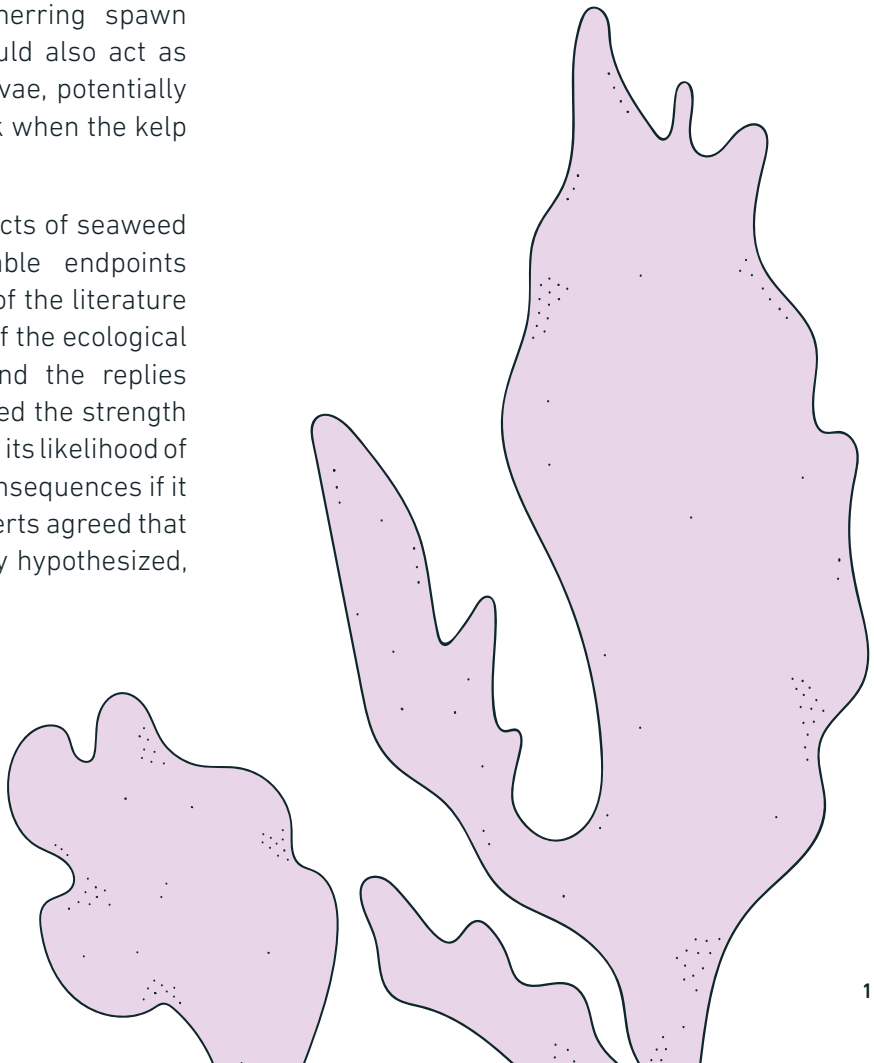
Benthic shading is seen as a substantial and uncertain risk for large farms of the size found in Asia; however, farms this large are unlikely to occur in the eastern North Pacific. Rather, any such impacts from the configuration of farms anticipated in the eastern North Pacific will be mitigated by the seasonal timing of growth and harvest. One interviewee described shading from farms as not substantially worse than that from spring phytoplankton blooms.

The attraction of species and changes in species interactions between co-occurring or dependent species were mentioned several times, and are a particular concern for regulators in Alaska. The main interaction mentioned was herring spawn on farmed kelp. However, farms could also act as fish attraction devices or entrain larvae, potentially increasing exposure to predation risk when the kelp is harvested.

Many of the potential ecosystem effects of seaweed aquaculture have direct, measurable endpoints (Table 1). Based on our assessment of the literature (particularly several recent reviews of the ecological effects of seaweed aquaculture) and the replies solicited from our experts, we included the strength of evidence for each effect, and ranked its likelihood of occurrence and the severity of the consequences if it does occur (Table 1). Broadly, our experts agreed that most of the effects are currently only hypothesized, as few have been assessed or observed, particularly in the eastern North Pacific.

Secondary effects, such as changes in food webs and biodiversity, could result through several of the pathways described as a consequence of the initial endpoints. These are noted in the text here, and in the Recommendations section, but are not included in the table.

The ecosystem effects of land-based aquatic plant culture (i.e., plants or plankton grown to harvest in onshore tanks) are less widely discussed in the literature, and were not seen as a major concern by the experts we spoke with. Generally, any potential effects from this aspect of the industry would be addressed through effluent management via required permits and established mitigation methods, primarily water filtration.



POLICY, REGULATORY AND LEGAL LANDSCAPE

BOX 6 : KEY ELEMENTS OF SEAWEED AQUACULTURE LEGISLATION, REGULATION AND POLICY IN B.C.

Currently, conditions of license are used to ensure that only wild-harvested seaweed seed stock is used for aquaculture in the eastern North Pacific (i.e., there is no domestication/selective breeding).

While there is no regulation around where seeds are sourced, the province currently uses conditions of licence to ensure growers harvest within 50 kilometres of the site, and from a minimum of 30 individuals.

Non-native species are currently prohibited in coastal aquaculture under conditions of licence, though no regulations are in place. Under conditions of licence growers must ensure that for aquatic species grown in tanks on land, no seaweed gametophytes or sporophytes and pathogens or parasites are introduced beyond the waters where they are naturally found.

The only current restriction on farm size in B.C. is a 520-hectare limit under the Land Act, which applies to all approved tenures. There is also no regulatory limit on farmed seaweed densities, although conditions of licence aim to mimic natural densities of aquatic plant beds to mitigate shading and potential for disease and pathogen transfer.

Conditions of licence for co-culture facilities that also have a federal shellfish licence typically require annual bottom and infrastructure surveys, although there is no guidance on the survey details required and this information is not currently actively requested for aquatic plant aquaculture.

JURISDICTION OF COASTAL WATERS IN BRITISH COLUMBIA

In B.C., all levels of government (Indigenous, federal, provincial and local) have some jurisdiction around coastal and marine planning, protection, management and enforcement, including issues pertaining to seaweed aquaculture. Regulating and managing sustainable seaweed aquaculture in B. C. is thus complicated in part by varying jurisdictions and sometimes-overlapping authorities of Crown and Indigenous governments.

In B.C., First Nations have sovereignty over their territories where Indigenous laws apply, as well as federal and provincial laws. First Nations sovereignty and territorial and traditional rights to marine resources are currently the subject of reconciliation negotiations for many of the First Nations along B.C.'s coast. On Crown lands, provincial and federal governments have a duty to consult with First Nations for any tenure applications to ensure that they do not affect Indigenous or treaty rights.

Provincial jurisdiction includes the foreshore to the low-water line (i.e., the lowest tide height over the past 20 years), as well as all "inland waters," meaning the seabed between headlands such as bays, harbours and coves (historically referred to as ***inter*** *fauces terrae*, "within the jaws of the land"). However, federal lands, including Port Authority land, are exempt, in that provincial laws may apply, but only to the extent that they do not interfere with federally regulated activities on those lands.

Beyond inland waters, Provincial law applies to the seabed of the territorial sea (extending from the low tide mark to 12 nautical miles offshore). The federal government has jurisdiction in the territorial sea and the Economic Exclusion Zone, which extends from 12 nm to 200 nm offshore.

There are grey areas when it comes to regulation, licensing and management of aquatic plants offshore. For example, the province issues licences for land tenures and aquatic plant management in areas off of the west coast of Vancouver Island, outside of inland waters, highlighting a gap in understanding which agencies have jurisdiction over aquatic plant aquaculture outside of inland waters.

As federal responsibilities regarding safe navigation (via Transport Canada) and protection of species at risk, fish and fish habitat (via Fisheries and Oceans Canada - DFO) intersect with the regulation and management of seaweed aquaculture regardless of location, responsibility for regulating, licensing and managing aquaculture in B.C. is currently shared across provincial and federal agencies, with input from First Nations through consultation and informed by local government, where appropriate. The overlapping responsibilities have created regulatory confusion, inefficiencies and gaps in enforcement. Furthermore, the relevant legislation has inconsistencies in standards and practices that do not adequately address environmental effects, thereby undermining sustainability efforts (Boyd 2007).

LEGISLATION AND REGULATIONS RELATED TO SEAWEED AQUACULTURE

The B.C. Ministry of Water, Land and Resource Stewardship (MWLRS) is the lead provincial agency for strategic policy and the primary authority for issuance and management of aquatic plant culturing in B.C. This includes tenure approval under the Land Act, and management of aquaculture sites under the B.C. FSA (Government of B.C. 2015). A harvest licence is required from MWLRS (under the B.C. FSA) if seaweed is grown for human consumption. To process the seaweed, a seafood processor licence from the B.C. Ministry of Agriculture and Food is required. The Ministry of Agriculture and Food is also the lead provincial agency for policy and aquaculture industry development. Federally, DFO is responsible for regulating, monitoring and licensing aquaculture operations for commercial fauna (i.e., fish and invertebrate species), though the infrastructure approval remains the responsibility of the province via the Land Act. DFO reviews seaweed aquaculture licence applications and assesses the potential for effects to fish and fish habitat and species at risk but does not otherwise regulate or monitor sites that grow only seaweed. DFO does co-regulate any aquatic plant co-culture with shellfish or fish aquaculture. Transport Canada is responsible for reviewing and approving the placement of aquaculture containment and/or structures within navigable waters.

Provincial regulations

The MWLRS is responsible for managing the culture of seaweeds that occurs on private and Crown land (or on Crown land covered by water), under part 2 of the FSA (Government of B.C. 2015), and for issuing land tenures for aquaculture on Crown land or in the marine environment under the Land Act (Government of B.C. 2025d). Once licensed under the FSA, growers must follow the reporting requirements according to Section 6 of the Fish and Seafood Licensing Regulation, as well as the additional requirements specified in their licensing agreement (the conditions of licence) and the associated management plan.

The FSA ("the Act") is focused on ensuring food safety, ensuring no possession of restricted aquatic plants, and indicating licensing requirements and duties of operators. In **Part 2**, the Act notes that a person must not possess or distribute for human consumption restricted aquatic plants except as authorized under a licence, permit or other authorization issued under an enactment of Canada or a permit issued by a licensing officer. Restricted fish and aquatic plants are subject to prohibitions or restrictions on harvesting under an enactment of Canada or an international agreement to which Canada is party. or that may be subject to inhumane or unsustainable harvesting practices. **Part 3 section 7** of the Act indicates that licensing officers can request information necessary to evaluate the application, refer the application to an inspector, a public officer and employee of Canada, or a person who has special expertise, and can issue the licence with or without terms or conditions or can reject the application. In addition, under **Part 3 section 10**, the licensing officer can vary, suspend or cancel an operator's licence. Specifically, **Part 3 section 11** of the Act a licensing officer can refuse to issue or renew, add terms or conditions on or vary, suspend

or cancel a licence if the officer believes doing so is necessary to protect or to prevent, reduce or address any adverse effect on all or part of a marine bed on which aquatic plants grow. While this last provision is focused on wild harvest, it is unclear how it may extend to seaweed cultivation.

The Fish and Seafood Licensing Regulation (B.C. Reg. 261/2016) ("the Regulation") under the FSA lays out information about expiry and period of licence term and record-keeping required by growers. It also classifies aquatic plants for applications and reporting (Appendix 1), and provides provisions for wild aquatic plant harvesting and processing. Record-keeping is focused on type and amount of seaweed harvested, who received the product and the dollar value.

The MWLRS also addresses aquaculture through the Land Use Operational Policy – Aquaculture ("the Policy"). The Policy applies to siting and improvements of tenures required for aquaculture, including cultivation of aquatic plants, on Crown land. This does not apply to ocean ranching or wild harvest of aquatic plants. The Policy describes the shared government roles and responsibility for aquaculture operations in the province; it does not apply to any aquaculture upland use (e.g., nurseries) or processing facilities on aquatic Crown land. The Policy states its support for sustainable development of the aquaculture industry: "the Provincial Government supports the sustainable development of the aquaculture industry and acknowledges aquaculture as a legitimate use of the coastal resource that makes decisions based on sound science and ensuring business practices are conducted in an environmentally, socially and economically sustainable manner." The Policy also describes the various types of Crown land tenures for aquaculture, including temporary licences, licences of occupation and leases, and maximum terms for each type. However, the Policy addresses shellfish and finfish aquaculture only, and aquatic plant aquaculture is interpreted through this lens. For example, the fee structure for aquatic plant aquaculture tenures is based on "shellfish land use value" under the Policy.

There are currently no policies or regulations specifically addressing potential ecological effects of seaweed aquaculture. However, provincial legislation and policy provide an avenue for management of the industry through conditions of licence, described in the licensing and management section below.

Federal legislation

As the agency responsible for managing all fisheries, and their potential effects on the marine environment including habitat and species at risk, DFO assesses the potential for effects on fish and fish habitat through the Fisheries Act and species at risk through the Species at Risk Act *(*SARA*)*.

The Fisheries Act is one of Canada's oldest environmental laws and plays a critical role in protecting fish and fish habitat. The relevant sections focused on protecting aquatic ecosystems and managing effects to ensure sustainable fish populations and ecosystems are summarized here. **Section 34.4** prohibits any activity that may harmfully alter, disrupt or destroy fish habitat without authorization. This includes activities that might damage the physical environment, water quality or food sources that fish rely on. **Section 35** prohibits construction or installation of barriers that would prevent fish from accessing their habitat, and **Section 36** bans deposit of any substances harmful to fish into waters used by fish. This includes industrial pollutants, waste or other substances that may degrade water quality and harm aquatic life. **Sections 20** to **22** are intended to ensure fish passage through fishways (structures that allow fish to pass around barriers like dams), mandating their maintenance and adequate water flow to ensure the free movement of fish within their habitat. **Section 40** provides for penalties and other enforcement measures for violations of the Act, including breaches of habitat protection or pollution prevention. The Act also gives DFO the authority to monitor, assess and enforce compliance, and enables collaboration with Indigenous groups and local stakeholders for habitat conservation and restoration.

Canada's Species at Risk Act is intended to protect endangered or threatened species and their habitats. Species at risk are assessed and classified by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), which provides independent scientific advice on the status of species. Listing species as endangered, threatened or of special

concern under SARA is at the discretion of the "competent" minister. Once listed, species and their habitats are provided protection from harm. **Sections 32-36** prohibit killing, harming, harassing, capturing or taking listed species, as well as damaging or destroying their critical habitat. The Act mandates the identification of critical habitat and its protection and restoration to prevent destruction or degradation from human activities, including fishing, development and pollution. These prohibitions apply specifically to federal waters, such as oceans and marine territories, and are enforced by DFO. While this would seem to lead to a jurisdictional gap in the B.C. marine space, DFO reviews all aquatic plant aquaculture licence applications and enforces SARA in the harmonized review process for aquatic plant cultivation licensing.

As the agency responsible for safe navigation, Transport Canada is responsible for administering Canada's Navigable Waters Act. This requires a review and authorization of the application for licence to ensure placement of aquaculture sites does not hinder navigation. If approved, compliance measures and any necessary impact mitigations are specified in the conditions of licence.

Marine spatial planning and management

Marine spatial planning and use management involves a systematic approach to allocating marine space for various activities and protections in the marine environment, including sustainable cultivation of seaweed. The process integrates ecological, cultural, social and economic considerations to support healthy ecosystems, a thriving marine economy and the rights and cultural values of coastal communities. By mapping out suitable areas for seaweed cultivation, rights-holders and stakeholders can ensure these activities support sustainable economic development without interference with other marine uses, such as fishing, marine transport or First Nations food, social, and ceremonial uses. Suitable areas are also spatially restricted to ensure the health of marine ecosystems.

In B.C., First Nations, the province, and the federal government have been working across a number of initiatives to develop comprehensive marine plans that consider ecological, social, and economic factors. These initiatives include First Nations Marine Plans, the Marine Plan Partnership marine plans, the Great Bear Sea Marine Protected Area network, the Pacific North Coast Integrated Management Area initiative and the Átl'ka7tsem/Howe Sound Marine Stewardship Initiative. Marine spatial planning initiatives led by Indigenous communities are grounded in the recognition of Indigenous rights, traditional knowledge and stewardship of marine resources, and reflect Indigenous perspectives and priorities, promoting sustainable management and conservation efforts that benefit both the communities and the ecosystems they depend on. These initiatives can also inform siting and management of seaweed aquaculture (under both the Land Act and the FSA) and are often referred to by decision-makers in granting tenures and licences. On their own, however, marine plans are considered recommendations, not regulations. Where legally enforceable restrictions are desired by plan participants (e.g., closure of bottom fishing in a certain area), other tools must be used (e.g., creation of a marine protected area designated under relevant legislation). Thus, if seaweed aquaculture sites are proposed in provincial protected areas, this would trigger review and management under the Provincial Park Act and Protected Areas of British Columbia Act.

B.C. Coastal Marine Strategy

Put forward in July 2024, the B.C. Coastal Marine Strategy (Government of B.C.2024) establishes the province's first shared, coastwide vision for the stewardship of marine resources. It outlines goals and actions for sustainable stewardship and coastal marine management within B.C.'s jurisdiction. Seaweed aquaculture management is prominent. Strategic themes include (a) healthy coastal marine ecosystems; (b) resilience to climate change; (c) thriving coastal economies and communities and (d) informed governance. Theme-specific actions and activities are identified and can be used to inform sustainability of the B.C. seaweed industry.

Indigenous laws and consultation

Federal and provincial governments are legally obligated to consult and, where appropriate, accommodate First Nations on decisions that could impact treaty rights or Indigenous rights and title. The Crown is therefore responsible for ensuring adequate and appropriate consultation and accommodations (Government of B.C. 2025b). The province also has the duty to consult under the Land Act, FSA and the Declaration on the Rights of Indigenous Peoples Act (DRIPA), and encourages seaweed growers to engage with First Nations early to build relationships and establish information-sharing processes. A database of First Nation contacts is provided (Government of B.C. 2025c).

In the past, colonial governments in B.C. did not consult with First Nations around any development in their territories. Beginning in 1990, these governments began examining how to make treaty with the majority of B.C.'s 203 First Nations with whom treaties were never signed. As a result, contemporary development in First Nations territories proceeds through a review and referral process.

The review and referral process is intended to respect Indigenous rights and integrates provincial and federal regulations. The province or federal governments typically refer project proposals to First Nations with overlapping traditional territory, allowing them to review potential effects, raise concerns and propose mitigation measures. Many First Nations have marine use plans outlining acceptable development based on ecological, cultural and economic priorities, which serve as key references during consultations. The process is often guided by co-governance agreements or reconciliation protocols between First Nations and the province. Accommodations such as project modifications, benefit-sharing agreements and enhanced environmental protections are negotiated to address concerns. Although complex, this collaborative approach aims to foster sustainable development while upholding First Nations' roles as stewards of B.C.'s marine environments.

Our review does not address Indigenous laws nor does it provide an Indigenous perspective on seaweed aquaculture. We recognize First Nations will have differing perspectives on the seaweed aquaculture industry, and on the governance and permitting decision process. We recommend a more comprehensive approach be undertaken with First Nations communities and governments to understand First Nations perspectives on governance and social, cultural, economic and ecological issues of the seaweed aquaculture industry.

LICENSING AND MANAGEMENT OF SEAWEED AQUACULTURE

The agencies and the execution of their role in the regulation of seaweed aquaculture, as described above, is referred to as a harmonized process. It is led by the province in collaboration with DFO and Transport Canada (Government of B.C. 2022). Staff from BC MWLRS, DFO and Transport Canada collaboratively review applications to operate an aquaculture facility in B.C. Applications are received through FrontCounter BC, and are reviewed by this federal-provincial "Project Review Team" for completeness and consistency with policy prior to being processed. Consultation with First Nations is done via the review and referral process. Municipal bylaws for zoning, processing and distribution of seaweeds are also considered. While the review process is collaborative, the agencies make independent decisions on applications based on their applicable legislation, policies and specific best management practices. New or amendment applications under the *Land Act* are also open for public review on a publicly accessible website, per

Section 32(2) of the *Land Act*, which requires Crown land applications to be published. Public participation in the administration of Crown land is encouraged and the site offers a platform for the public to submit comments.

Aquatic plant culture applications are reviewed to ensure that aquatic plants entering the food chain are safe for consumption, and that aquatic plant culture does not negatively affect the marine environment. A lack of any specific provincial regulatory requirements or policy guidance around ecological effects of seaweed cultivation means the province uses tenures and conditions of licence to address potential ecological effects and management measures. Applications can be made for new seaweed cultivation licences/tenures or to amendment existing licences/tenures. There are separate application processes for land-based (nurseries and aquaculture) facilities and marine grow-out operations.

For marine grow-out operations, the province reviews an application under the Land Act to grant a licence for tenure. The application addresses the type of tenure, farm siting (including depth, and distance to specific types of habitats) and infrastructure, types and amounts of seaweed to be cultivated and seed sourcing. Relevant sections of the application become a management plan signed by the applicant and province. Adherence to the management plan is required under either the tenure agreement under the *Land Act* or the conditions of licence under the FSA aquatic plant culture licence where there is no *Land Act* tenure (e.g., upland nurseries on private land). A management plan is also required for handling potential marine debris. To this end, the conditions of licence and management plans do include some ecological considerations (Table 2). Depending on the application a wild harvest application is also needed for sourcing seed material, and a licence under the FSA is needed if the seaweed is intended for human consumption.

With respect to ecological effects, the primary regulations available to the project review team are DFO's Fisheries Act and SARA. DFO will review the risk of the operation to fish and fish habitat under the Fisheries Act, and to listed species at risk under SARA, according to each species' recovery strategy or action plan. For example, if siting in for species-at-risk critical habitat, a third party may be required to complete an impact study to ensure that introducing seaweed aquaculture farms to the area would not harm these species. Beyond this, there are few regulations or policy guidance for seaweed aquaculture in B.C. Thus, any current conditions or mitigation measures (see Box 7 - Table 2) are based on best practices identified by the project review team and are part of the conditions of licence and farm management plan.

Site selection

Desirable sites, from the growers' and regulators' perspectives, include factors such as high seawater exchange, upwelling of nutrients, protection from storms and low likelihood of interactions with marine habitats and species at risk, all with ease of access to processing and markets. Some growers also consider proximity to historical kelp beds, as spores from the farms may help restore these beds (Lang-Wong 2022). Growers are also encouraged to work collaboratively with First Nations partners to avoid areas that are important for traditional or other marine uses.

Aquaculture is not allowed in salt marshes and is discouraged from occurring in areas shallower than the 10-metre bathymetric contour to avoid impacting sensitive habitats such as eelgrass. The project review team also wants growers to avoid rocky reef habitats, kelp beds, fish spawning areas, glass sponge complexes (*Hexactinellidae*) and/or coral complexes. Rockfish Conservation Areas, Geoduck Management Red Zones, designated critical habitats and provincial Wildlife Management Areas are also to be avoided. In areas where sensitive habitats may occur but the risk is deemed to be low, best practices and mitigation measures are suggested. If areas are deemed high risk, the review team provides additional guidance, potentially suggesting relocating the farm.

Tenure type and length of licence

The province currently grants licences of occupation for aquatic plant aquaculture (or a lease for land use, although these are not typically granted for aquatic plant aquaculture). Licences of occupation are issued for up to 30 years. However, when growing for food,

the Fish and Seafood Licensing Regulation limits a licence to 10 years. If growers are producing seed for their own farms, they also require an annual wild harvest licence, if the seaweed is intended for human consumption or if they harvest more than 100 kilograms wet weight.

Extent and type of culture

Farm size in B.C. is currently limited to 520-hectares under the Land Act, which applies to all approved tenures. This is the only legal restriction on farm size. There is no regulatory limit on farmed seaweed densities, although conditions of licence aim to mimic natural densities of aquatic plant beds to mitigate shading and potential for disease and pathogen transfer. Conditions of licence are also used to prohibit non-native species in seaweed aquaculture as no regulations are in place.

Infrastructure

The application includes drawings of all planned infrastructure, including anchors and anchor lines, line densities, depths of works, and distances from infrastructure to the seabed and the low-water line. Any proposed substrate modification is also required. These requirements are part of the conditions of licence to address infrastructure effects. Care and maintenance of the site are also expected, per debris management plans. The only relevant regulations governing infrastructure are those required by Transport Canada to ensure visibility, including having floats with permit numbers and having lights.

Seed stock

With no regulation around where seeds are sourced, the province currently creates conditions of licence requiring growers to harvest within 50 kilometres of the farm, from a minimum of 30 individuals. This is based on best management practices from Alaska and has been updated from discussions with geneticists and studies showing limitations of genetic diversity resulting from fewer than 30 crosses in the lab. This is done to maintain natural levels of genetic diversity, as a higher number of parents will yield higher genetic diversity. The selected sori should be free of biofouling with no conspicuous diatoms or invertebrates. A wild harvest licence is needed to harvest these individuals if the resulting seaweed from the out-planting is for human consumption. This is required every year unless biobanking occurs and seed can be developed in the lab (likely maximum of five years) or seed is sourced from another licensed operation, which would obtain the proper wild harvest license and nursery aquatic plant licenses. These management practices maintain genetic diversity and limit introductions of non-native species.

Harvest timing

Although there are no regulations around when out-planted seaweed must be harvested, regulations around fish and fish habitat may lead to conditions of licence that address harvest timing. For example, if the area is known to be used by Pacific herring for spawning, the grower may be encouraged to harvest prior to known spawning timing. If spawning on kelp does occur, the farm is designated as essential fish habitat and harvest is prohibited until after hatching and the habitat designation is removed. This typically leads to degradation of seaweed quality and often loss of the crop.

Nursery practices

Seaweed nurseries require a licence for seaweed to be grown for out-planting, for growing phytoplankton or for seaweed intended for human consumption. The management of water quality sourced and released is addressed in the conditions of licence. Upland nurseries are required to include a process for sterilization such as autoclaving, tyndallization (i.e., repeated boiling), pasteurization, filtration or ultraviolet (UV) irradiation, to protect human health and minimize potential for disease transfer.

Marine debris management plans

Conditions of licence are used to discourage the release of refuse and debris into the marine environment. A debris management plan is required for all applications, outlining how infrastructure, gear and equipment will be managed to minimize generation of debris and ensure that any debris generated during operations and decommissioning does not enter the marine environment.

Reporting and enforcement

Existing regulations require little monitoring and reporting for licensed seafood growers. Under

the FSA, growers must keep records about the types and quantities of seafood grown. For plant aquaculture, this includes the aquatic plant group and species, and information on distribution (quantity, person to whom aquatic plants were distributed and amount received for aquatic plants). Conditions of licence for co-culture facilities that also have a federal shellfish licence typically require annual bottom and infrastructure surveys, although there is no guidance on the survey details required and this information is not currently requested for aquatic plant cultivation. If required by the debris management plan, the conditions of licence also require reporting any incidents of entanglement and on any debris or pollution released. The current policy for aquaculture is to use conditions of licence and management plans to address compliance inspections, monitoring and enforcement actions, which are coordinated between MWLRS, Ministry of Environment and Climate Change Strategy and in cooperation with DFO.

BOX 7 : TABLE 2 : EXISTING MITIGATION MEASURES

Table 2. Existing mitigation measures and their enabling legislation for managing potential ecological effects of seaweed aquaculture in British Columbia.

RESPONSIBLE	MANAGEMENT LEVER (LEGISLATION)	MITIGATION MEASURE	ECOLOGICAL ENDPOINT(S)
Province of BC	Conditions of licence - Location/Extent of Operations (Land Act, Fish and Seafood Act - FSA)	No installation of any aquaculture structures or activities in waters shallower than 10 m bathymetric contour	Competition for light; Altered benthos; Altered species distributions; Altered water chemistry; Blooms of macro-algal pest species
		Distances from seabed to infrastructure	Competition for light
		Proposed infrastructure - ensure anchors are not in sensitive habitats and minimize substrate modification	Altered benthos (nearshore); Competition for light; Altered species distributions; Altered food webs/ biodiversity
		Densities of longlines	Competition for light; Competition for nutrients; Pathogens and disease; Blooms of macro-algal pest species; Entanglements of megafauna
	Location/Extent of Operations (Wildlife Act, Land Act)	Aquaculture activities not permitted in Wildlife Management Areas	Altered habitats/species distributions; Entanglements of megafauna
Fisheries and Oceans Canada	Location/Extent of Operations (Species at Risk Act)	Aquaculture activities must not result in harm to SARA listed species, their residence, or critical habitat	Altered habitats/species distributions; altered food webs; Entanglements of marine megafauna
	Location/ Extent of Operations (Fisheries Act)	Assess risk from infrastructure and operations to listed sensitive habitats and conservation areas. See text for details.	Altered benthos (nearshore); Altered habitats/species distributions; Entanglements of megafauna
Province of BC	Conditions of licence Culture and harvest practices (FSA)	Species to be cultured and harvested - non-native species not allowed	Species introductions
		Seedstock - Sourced from at least 30 individuals from within 50 km site	Genetic disruption; Pathogens and disease; Species introductions
	Culture practices (Land Act, FSA)	Biosecurity measures required in culture facilities for seedstock and outplanting	Pathogens and disease; Species introductions; Marine Pollution
	Conditions of licence - Debris Management (Land Act)	A debris management plan to minimize the generation of debris and ensure that any debris generated does not enter the environment.	Marine pollution/debris

RECOMMENDATIONS FOR IMPROVING PRACTICE AND AVOIDING NEGATIVE ECOLOGICAL EFFECTS

Seaweed aquaculture is a new and expanding industry in B.C. The existing B.C. aquaculture legislation and policy were developed primarily for shellfish and finfish aquaculture, with the focus on safe consumption for people. Jurisdiction over environmental effects from shellfish and finfish aquaculture falls to the federal government. Thus, the current regulatory framework and policies do not meet the needs of the seaweed aquaculture industry and regulators. This is the basis for our primary recommendation, that a comprehensive conversation between all levels of government be undertaken to review and update potential ecological effects, particularly with respect to coastal communities, and address the relevant governance structures, in the context of DRIPA.

Here, we first review opportunities to revisit the regulations and policy for managing seaweed aquaculture. We then summarize management practices recommended in the published literature, and guidance suggested from our interviews with regulators from Alaska, B.C., Washington and Nova Scotia. Table 2 provides an overview of how existing management practices are intended to mitigate potential ecological effects in B.C.

UPDATING THE REGULATION AND POLICY FRAMEWORK

Flexibility in the legislative tools allows the B.C. team to manage for sustainable seaweed aquaculture through conditions of licence. However, a lack of specific regulations and transparent policy could lead to negative ecological effects and ultimately translate into poor outcomes. A key gap is that the B.C. FSA does not apply to aquaculture products that are not for consumption. These farms are only issued a tenure under the Land Act, and do not require a licence under the FSA. Updating the FSA and Fish and Seafood Regulations would help clarify and strengthen protections for the nearshore marine environment. Regulations and provisions for wild harvest of seaweeds should be included. However, new or amended legislation takes time, and requires underlying policy. Thus, updating the current B.C. Land Use Aquaculture Policy with a policy for seaweed aquaculture is a critical first step . The B.C. Coastal Marine Strategy includes recommendations to modernize policies and procedures and is informing an updated seaweed aquaculture policy for B.C. anticipated to be completed by the end of 2025 (Kevin Romanin, International Seaweed Symposium, May 5 2025), with the expectation of increasing clarity and transparency.

Federally, legislation in Canada includes protection of species at risk, fish and fish habitat and marine mammals. However, this legislation is weakened by ministerial discretion (Boyd 2007). Environmental protection would be improved with stronger federal environmental leadership, more comprehensive and specific legislation with enforceable standards and timelines, stronger enforcement and higher penalties to improve compliance, and greater resources for relevant agencies (Boyd 2007). Additionally, environmental governance is frequently left to the provinces, leading to inconsistencies, reduced transparency and weaker overall protections due to jurisdictional limitations.

Recently, Turcotte et al. (2021) provided recommendations to strengthen the Species at Risk Act to improve accountability and efficiency. Greater transparency on how decisions are made and addressing gaps in legislation would also be welcome. A key gap in the development of the seaweed industry is the absence of any legislation for offshore aquaculture. Since provincial jurisdiction ends 12 nautical miles from the outer coast, no B.C. legislation is likely to apply beyond this limit. While there is currently no aquaculture taking place offshore, federal policy and legislation are urgently

required given the growing calls to expand to these regions to sink seaweeds and even entire farms for carbon sequestration (García-Poza et al. 2020, Pessarrodona et al. 2024).

Alleway et al. (2023b) offer a range of practices for restorative aquaculture that could serve as precautionary best practices for any jurisdiction. They define restorative aquaculture as a practice that provides and accrues direct ecological benefits for net positive outcomes. These include farm siting to support water filtration and denitrification, increase oxygenation and provide additional habitat, as well as engaging practices that reduce local acidification or effects on other species (e.g., co-culture) and provide opportunities for carbon sequestration.

Policy around multi-species integrated multi-trophic aquaculture (IMTA) methods that provide for both synergistic sharing of nutrients and a reduction in water eutrophication (Tullberg et al. 2022) would also be useful. Multi-trophic methods benefit both kelp and co-cultured shellfish species, and generally reduce waste from both (Ramli et al. 2020, Zhang et al. 2022).

SPATIAL PLANNING TOOLS AND GUIDANCE

In Canada and the U.S., divided jurisdiction of the marine space requires cooperation between the responsible agencies. In B.C., a harmonized single application process for seaweed aquaculture helps, but the process can be time-consuming and lacks clarity on how decisions are made. Currently, industry members are generally proactive and maintain social licence by participating as good actors. However, improved guidance and transparency will help ensure a sustainable future by providing clarity to permit applications and operations.

While there is some guidance for aquaculture in B.C. — e.g., an infographic from DFO (Fisheries and Oceans Canada 2025), a website with information on application process (Government of B.C. 2025a) and consideration of aquaculture in some marine plans (e.g., MaPP) — the guidance is limited and fractured. The application portal consists mainly of harmonized application forms, with few resources to support the applicant.

In constrast, the Alaska Aquaculture Interagency Working Group has developed a guidance document (Bishop 2021) that provides a clear description of the permitting process and details the responsible agencies at each step (Appendix 2). Alaska also provides a comprehensive portal (https://akaquaculturepermitting.org/) that includes siting guidance and mapping tools to allow applicants to select sites and create standardized maps and applications. This allows proponents to identify in advance where seaweed aquaculture can occur and where it should be restricted, thereby reducing time and effort for all parties. Such tools improve transparency and efficiency, and would increase buy-in from federal, provincial and First Nations governments. Establishing the necessary dialogue between industry, regulators and governments would also be improved with such a process.

MONITORING, RESEARCH AND REPORTING

Monitoring and evaluating outcomes is essential for effective and adaptive management. Currently, there is little monitoring and reporting required from B.C. seaweed aquaculture operators under their conditions of licence. Given the potential growth of industry and the need to improve our understanding of seaweed aquaculture effects, additional monitoring and reporting should be integrated into any updated policy. This is particularly relevant for seaweed aquaculture placed in or near areas of important and critical habitats where species may benefit from, or be negatively impacted by, the industry. However, monitoring and reporting programs can be extensive and costly, so it is important monitoring obligations are well-defined and the data suitable for understanding effects and informing adaptive management (Wilding et al. 2017, Campbell et al. 2019). A monitoring and reporting framework for seaweed aquaculture should be included in updated policy documents. It should be developed through an equitable and transparent participatory process, ensure that conditions of licence are being met, and connect transparently back to management recommendations. Considerations for monitoring kelp mariculture in Washington State provide some useful guidance (Buckner et al. 2024).

In addition to monitoring, regulators should consider co-developing research with industry, researchers, regulators and local governments to further understand potential ecological effects and mitigation measures. For example, investigating the trade-offs of allowing crop on lines to remain in the water, balancing the benefits of providing habitat against a risk of entanglements and possible gene flow from cultivated seaweeds to wild populations.

ENDPOINT-SPECIFIC MEASURES

Risks and mitigation measures have been described in the literature, and many potential negative effects of seaweed farming could be lessened by applying existing mitigation strategies (Campbell et al. 2019). These include, but are not limited to, appropriate siting to minimize damage to sensitive environments; using seed sources that reflect the genetic diversity of local wild stocks; restricting cultivation of non-native species; using biosecurity measures to control the spread of diseases, parasites and non-natives; restricting fertilization; and properly maintaining infrastructure (Campbell et al. 2019). Some of these are addressed in B.C. through conditions of licence. However, there are few guardrails in place to identify and addres potential negative ecological effects. Here we describe practices that can be implemented to mitigate potential effects from seaweed aquaculture operations, and how some mitigation measures can address several potential endpoints.

Ecological interactions with seaweed farms are influenced by the location, scale and density of the farm, as well as the type of operation and the species cultivated. This makes siting criteria of critical importance in managing potential effects. There is general agreement that there are likely to be greater ecological effects from farms with larger spatial footprints and greater densities (e.g., (National Academies of Sciences 2021, Bhushan et al. 2023). Thus, some jurisdictions have enacted size limits for seaweed farms. For example, in Maine, an experimental farm lease is limited to four acres (1.6 ha) and three years, while a standard commercial lease is valid for 10 years, is renewable and can be up to 100 acres (40.5 ha). Alaska restricts the spatial footprint of seaweed aquaculture relative to its location. For example, only one seaweed aquaculture operation can occupy up to one third of an embayment or area of coastline. This is largely to address conflicts with marine uses but may also help avoid or reduce ecological effects.

Currently, there are no reasonable limits on the size of seaweed aquaculture operations in B.C., (no farm is likely to approach the size of the current 520 ha tenure limit). While there is no research on the ideal farm size, precautionary policies around size and density should be considered in an updated seaweed aquaculture policy and adapted as information becomes available.

Competition for nutrients and light

B.C. coastal waters are generally high in nutrients due to regional upwelling. However, offshore waters and some nearshore areas may be more oligotrophic. In these locations, seaweed aquaculture could lead to competition for nutrients with phytoplankton. Any effects of benthic shading by farms will also depend on site, as this will influence the composition of the benthic community. These effects would be mitigated by siting seaweed farms in areas of high nutrient delivery (which will also improve seaweed growth), reducing individual farm size and their cumulative areal extent, reducing farm densities and removing lines after harvest.

In B.C., conditions of licence are used to reduce effects of benthic shading by siting farms to avoid hard-bottom sites where benthic seaweeds occur, and sensitive habitats like eelgrass. Farm density is also managed through conditions of licence.

Changes to food webs, biodiversity and water chemistry

Seaweed aquaculture may impact food webs and biodiversity by providing physical habitat and increasing primary production. The evidence of structural habitat provision by seaweed is strong: fish and invertebrate species use the habitat for foraging, shelter, settlement and spawning (Visch et al. 2020). In intertidal systems, foraging birds may shift their use of space for foraging in response to farm siting, and seaweed aquaculture may favour some species over others (Martínez-Curci et al. 2023). This can be positive for biodiversity, but negative effects could arise if species move to less

suitable habitat, or if food web dynamics are altered. Siting of farms away from important habitats, timing farm operations and seasonal removal of fallow infrastructure can mitigate these effects. Benthic effects, either as accumulation of particulate organic matter under farms, or due to active sinking for carbon sequestration, can also alter food webs as influxes of organic material may affect the local fauna.

Larger farms can also influence water chemistry. For example, seaweed farms can reduce local acidification, providing a valuable service to co-cultured shellfish, particularly in an acidified ocean. However, hypoxic and anoxic conditions could occur if large inputs of seaweeds are sunk for carbon sequestration or lost to intertidal areas. More information is needed to fully understand these effects, emphasizing the importance of iterative policy development as new information becomes available.

Species introductions and changes in species distributions

Along with inputs of organic matter, artificial structures can also change the distribution and habitat use of seaweeds, invertebrates and fish. Farm infrastructure can both introduce substrates for organisms to attach and attract fish and invertebrate communities. Biofouling is common and could introduce species that aren't typical at the farm location. More direct species introductions can be mitigated with improved standards of practice and thorough bioscreening procedures in nurseries, and regulations that restrict farms to using native species in seaweed aquaculture.

Temporal overlap of farm operations with native species habitats influences these interactions. Many potential effects are mitigated because growth and harvest in the eastern North Pacific occur from mid-winter to late spring (November to May). Removal of infrastructure during the off-season would further help, as the highest fish abundance is typically between June and November. In B.C., it is currently common practice to harvest all the seaweed and remove longlines during the off-season, although some farmers have tested leaving 10 per cent of seaweed out for carbon cycling and to support habitat use. Clearer guidelines on what is expected in terms of practice and monitoring would ensure consistency of this practice and lead to a better understanding of the ecological interactions.

Farm siting guidance would mitigate these effects, and bottom surveys of substrates and local communities prior to operations would help with site selection. Once infrastructure is in place, monitoring farms for species usage, particularly at-risk species like northern abalone or important forage fish like Pacific herring, will be important for ensuring such species are not affected during harvest or decommissioning.

Blooms of macroalgal pest species

Larger farms with higher densities are more likely to cause blooms of macroalgae that can impact the seaweed farms as well as nearby ecosystems, while smaller, less dense farms may reduce excess nutrients and reduce availability to harmful phytoplankton. In areas with lower nutrients such as offshore sites, fertilization has been proposed. While not currently used in B.C., restricting fertilizer use, particularly across large spatial extents or in nearshore areas, would help reduce the potential for pest blooms.

Genetic disruption

Seaweed farm sites could influence the genetics of local, wild stocks of seaweeds. To maintain natural levels of genetic diversity, conditions of licence in B.C. require growers to harvest a minimum of 30 individuals within 50 kilometres of the grow-out site for sourcing their spores. This practice was adapted from Alaska, which requires 50 individuals harvested within 50 kilometres based on genetic studies done on *Alaria* species. Best practices also suggest sourcing parent material from different locations every year, and to fully harvest the farm in the spring prior to spore release from cultivated plants. A recent study of the genetic stocks of bull kelp and giant kelp in B.C. shows high genetic drift in kelp populations, except for some isolated populations, meaning there is greater connectivity across large areas of the ocean than was expected (Bemmels et al. 2024). For aquaculture species *S. latissimi* and *A. marginata*, there is limited research in Canadian waters. Additional information on these species would help

inform optimal sourcing and crossing of populations for restoration and aquaculture. An updated policy would emphasize the need to review and update the 50-kilometre rule as more information comes to light on genetic diversity in wild populations, and the likelihood of their genetic disruption.

Pathogens and disease

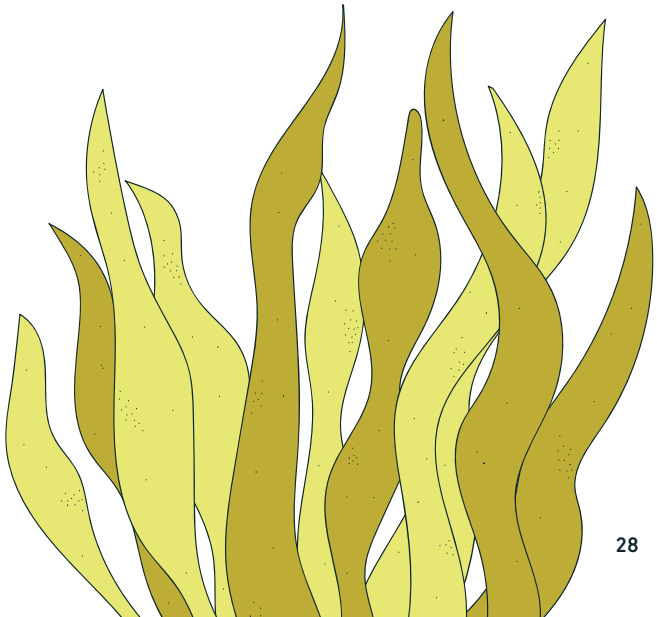
As with other ecological effects, larger farms tend to have a higher incidence of pathogens and disease (Brown et al. 2020, Ward et al. 2020, Zhang et al. 2022). While little is known about seaweed diseases in B.C., existing conditions of licence for managing and treating water from nurseries and land-based facilities are intended to reduce disease transfer. For in-water farms, existing limits on seed sources (above) may reduce spread of pathogens and pest species. Limits on farm size, cultivation line density and regional farm density also help reduce the prevalence of disease. Restricting cultivation density could be applied on a species-by-species basis, with different species having specific density conditions based on their sensitivity to crowding. Disease outbreaks would also be mitigated by restricting the movement of material between sites, standardized monitoring and culling infected crops. Biosecurity measures such as farm hygiene, inspection, lab testing, quarantine and regulations and procedures for import and transplant should be clarified and updated as more information on pest and pathogen risks for seaweed species becomes available.

Entanglements of megafauna

No entanglements of marine mammals with seaweed aquaculture infrastructure have been reported, with the risks of entanglement largely mitigated by maintaining taught anchor lines to the ocean floor (Campbell et al. 2019). The use of weak links or lines to further reduce risk of entanglement is being investigated, but loosening or releasing taut lines on aquaculture farms may increase the likelihood of entanglement for interacting megafauna. Similarly, acoustic marine mammal deterrence devices are species-specific, and could harm some species. Farm siting and management could also consider seasonal marine mammal habitat use. Larger farms in deeper, more exposed waters where megafauna are more likely are rare (Fujita et al. 2023) but are anticipated to increase (ICES 2023). Restricting aquaculture in migration pathways or during times of high marine mammal density would further mitigate potential entanglements, although this may be impractical for wide-ranging species.

Marine pollution and debris

The primary pathway for pollution from land-based aquaculture farms is effluent discharge. Effluent restrictions and recirculation would mitigate associated risks. For marine-based farms, the primary pathways are marine debris and noise and light pollution from operations. Noise and light pollution are largely limited to installation and decommissioning, and can be mitigated with timing rules that reduce the potential for effects on noise- and light-sensitive species. Light pollution during operations may occur as lights are required to reduce navigational hazard. For marine debris, a management plan is required as part of the conditions of licence, which typically require the debris management plan to include removing infrastructure in the off-season to avoid loss of material, and monitoring and cleanup of any debris that does occur. However, monitoring and enforcement are very limited, thus the policy relies on industry members to be good actors. In eastern Canada, a cleanup bond is required, where growers pay the Aquaculture Association as insurance against marine debris in case abandoned farms need to be decommissioned. In B.C., conditions of licence also require a security deposit to help reduce marine debris from abandoned farms, but the amount set aside is typically less than what is required and should be increased before significant expansion of the industry.

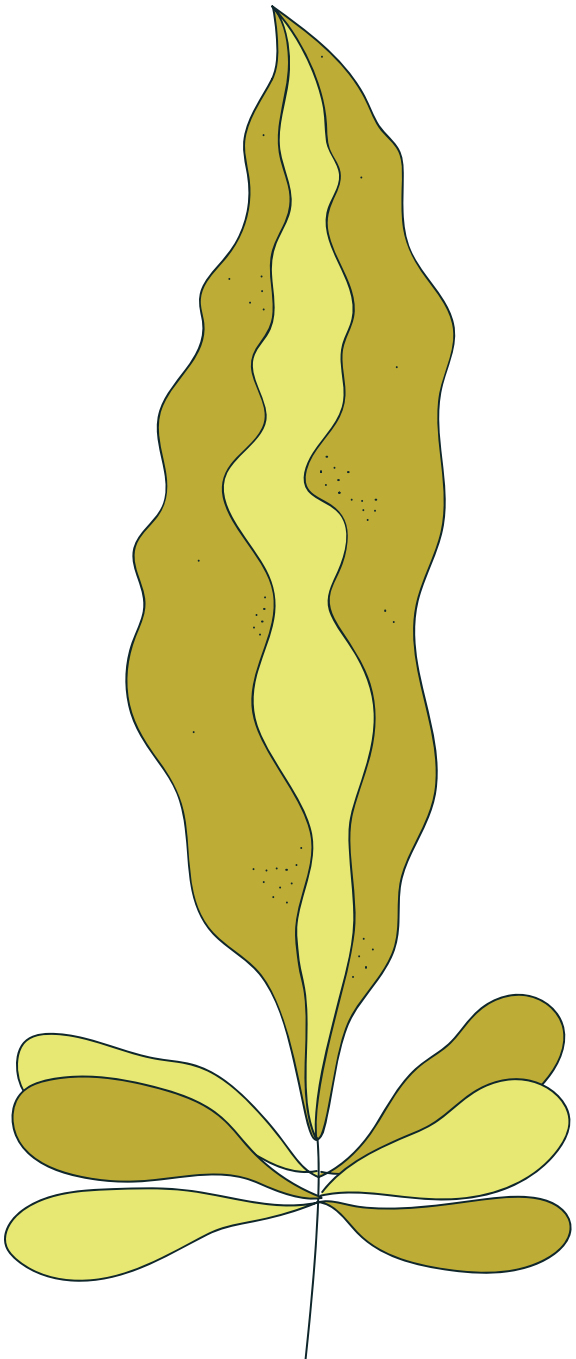


CONCLUSIONS

Seaweed farming in B.C. has the potential to transform coastal social and ecological systems. The specific outcomes of this transformation will depend largely on how the industry grows and the way farms are developed and managed. In this report we describe, and highlight gaps in, the regulation of seaweed aquaculture in B.C. We compare regulation of the industry to other jurisdictions in Canada and the eastern North Pacific, identify gaps in aquaculture regulation in B.C. and offer recommendations for updating policy.

While the use of conditions of licence in B.C. in the absence of specific regulations provides flexibility to managers to tailor and adapt licences to site-specific considerations and to new information, the lack of specific regulations and an opaque seaweed aquaculture policy could eventually lead to negative ecological effects and poor outcomes for industry. Given that regulations take time to change, an updated seaweed aquaculture policy from the province, which could be done promptly, will provide necessary, immediate guidance and transparency for the industry.

A broader discussion to address the regulatory gap around offshore seaweed aquaculture is also critical. Our key recommendation, the engagement of a broad discussion on ecology and governance with First Nations and federal partners, would pave the way for updated policy and regulations that consider all potential effects, not just food safety and land use. However, since much remains unknown about this nascent industry, it will be important for new policies to remain flexible and responsive to new information.



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APPENDIX 1:

AQUATIC PLANTS LISTED IN THE BRITISH COLUMBIA FISH AND SEAFOOD ACT

(the original text from the Act is abridged)

The notation "spp." refers to all species within the genus preceding the notation.

GROUP 1 AQUATIC PLANTS

The following species of aquatic plants are classed within group 1:

(a) *Macrocystis integrifolia;*
(b) *Nereocystis luetkeana.*

GROUP 2 AQUATIC PLANTS

The following species of aquatic plants are classed within group 2:

(a) *Agarum spp.;*
(b) *Alaria spp.;*
(c) *Costaria costata;*
(d) *Cymathere triplicata;*
(e) *Egregia menziesii;*
(f) *Eisenia arborea;*
(g) *Saccharina sessile;*
(h) *Laminaria spp.;*
(i) *Pleurophycus gardneri;*
(j) *Pterygophora californica.*

GROUP 3 AQUATIC PLANTS

The following species of aquatic plants are classed within group 3:

(a) *Agardhiella tenera;*
(b) *Ahnfeltia spp.;*
(c) *Endocladia muricata;*
(d) *Gelidium spp.;*
(e) *Gloiopeltis furcata;*
(f) *Gracilaria spp.;*
(g) *Gracilariopsis sjoestedtii;*
(h) *Gymnogongrus spp.*

GROUP 4 AQUATIC PLANTS

The following species of aquatic plants are classed within group 4:

(a) *Gigartina spp.;*
(b) *Iridaea spp.*

GROUP 5 AQUATIC PLANTS

The following species of aquatic plants are classed within group 5:

(a) *Cystoseira geminata;*
(b) *Fucus spp.;*
(c) *Sargassum muticum.*

GROUP 6 AQUATIC PLANTS

The following species of aquatic plants are classed within group 6:

(a) *Enteromorpha spp.;*
(b) *Monostroma spp.;*
(c) *Porphyra spp.;*
(d) *Rhodymenia spp.;*
(e) *Ulva spp.*

GROUP 7 AQUATIC PLANTS

The following species of aquatic plants are classed within group 7:

(a) *Phyllospadix spp.;*
(b) *Zostera marina.*

GROUP 8 AQUATIC PLANTS

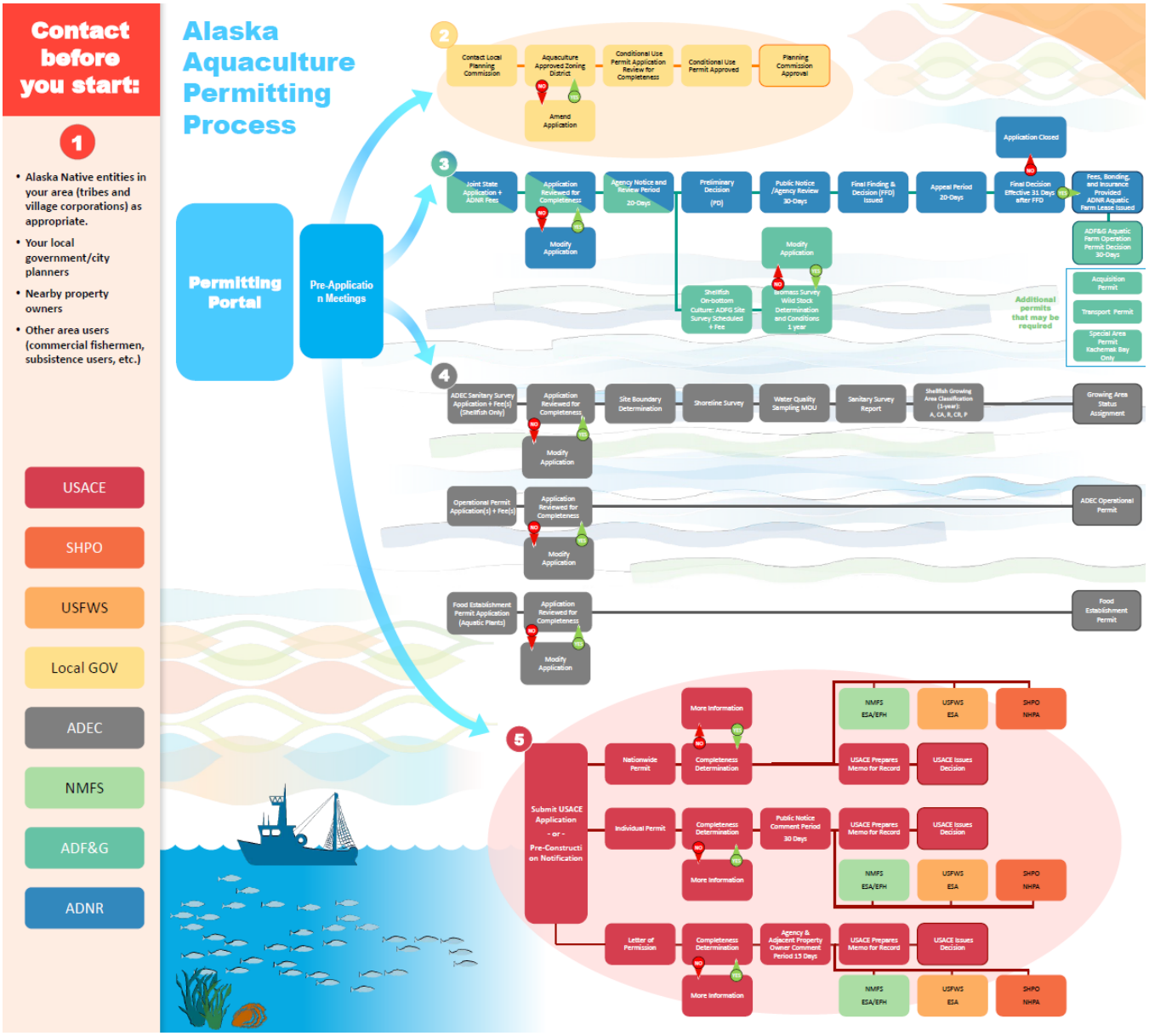
Salicornia spp. are classed within group 8.

GROUP 9 AQUATIC PLANTS

All species of aquatic plants not classed within any of groups 1 to 8 are classed within group 9.

APPENDIX 2:

ALASKA AQUACULTURE PERMITTING FLOWCHART



Source : https://akaquaculturepermitting.org/

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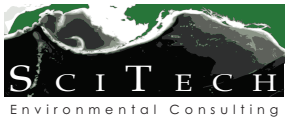
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