



Situation Analysis for Washington's Emergent Kelp Aquaculture Industry

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Abbreviations and acronyms

ARPA-E	Advanced Research Projects Agency-Energy	NOAA	U.S. National Oceanic and Atmospheric Administration
BaP	benzo[a]pyrene	NWIFC	Northwest Indian Fisheries Commission
CASS	Coastal Aquaculture Siting and Sustainability	NWSC	Northwest Straits Commission
CO ₂	carbon dioxide	ORIA	Washington Governor's Office for Regulatory Innovation & Assistance
DNR	Washington State Department of Natural Resources	PAH	polycyclic aromatic hydrocarbon
DOE	U.S. Department of Energy	PBDE	polybrominated diphenyl ether
DOH	Washington State Department of Health	PCDF	polychlorinated-dibenzofuran
ECY	Washington State Department of Ecology	PFAS	per- and polyfluoroalkyl substances
FAO	Food and Agriculture Organization of the United Nations	PNNL	Pacific Northwest National Laboratory
FDA	U.S. Food and Drug Administration	PSRF	Puget Sound Restoration Fund
HACCP	Hazard Analysis Critical Control Point	RCW	Revised Code of Washington
ICES	International Council for the Exploration of the Sea	SEPA	State Environmental Policy Act
JARPA	Joint Aquatic Resources Permit Application	SMP	Shoreline Master Program
MARINER	Macroalgae Research Inspiring Novel Energy Resources	SOAL	state-owned aquatic lands
MHSS	Maaqutusiis Hahoulthee Stewardship Society	TNC	The Nature Conservancy
MLLW	mean lower low water	U&A	Usual and Accustomed Fishing Area
MLW	mean low water	USACE	U.S. Army Corps of Engineers
NAV	native aquatic vegetation	U.S.C.	U.S. Code
NGO	nongovernmental organization	USFWS	U.S. Fish and Wildlife Services
NIMBY	not in my backyard	WAC	Washington Administrative Code
		WDFW	Washington State Department of Fish and Wildlife
		WHO	World Health Organization
		WSC	Washington Seaweed Collaborative
		WSDA	Washington State Department of Agriculture
		WSG	Washington Sea Grant

Seaweed / kelp terminology

Throughout this report, we often use the word *seaweed* to describe the relevant aquaculture industry and wild species. We use the term *kelp* when referring to a subset of brown seaweeds. While this report primarily focuses on kelp aquaculture, there are instances where seaweed species other than kelp are also included in the narrative.



Section 1:

Understanding the potential

Key takeaways

- The seaweed aquaculture industry is growing globally, and there is both interest and opportunity to farm sustainably grown seaweed in Washington state.
- When done well, seaweed aquaculture can benefit both communities and the marine environment.
- Seaweed is an important first food for coastal Pacific Northwest Tribes and serves as a critical part of their social, cultural, and spiritual existence.
- Early collaboration and deep relationship building with Tribes should be prioritized before, during, and after any permitting for seaweed aquaculture.
- Washington state is home to over 600 species of native seaweeds, including many that could be suitable for commercial applications when sited, grown, and harvested responsibly.
- Native bull kelp populations are in decline, likely due to long-term increases in water temperature combined with nutrient availability and low current speeds. Understory kelp populations have been studied less due to the difficulty of underwater monitoring.
- Washington seaweed aquaculture farms are rooted in early seaweed research collaborations, and new farms continue to express interest in and an intent to continue conducting research.
- A limited number of active seaweed farms exist in Washington waters, but potential growers have shown interest in seaweed farming and want to learn more about the options, which has led to an active seaweed community.

Introduction

This situation analysis provides an overview of the current state of the kelp aquaculture industry in Washington for the community of farmers, scientists, Tribal, federal, state, and local government representatives, and for people interested in the potential uses of cultivated kelp. This document explores the industry’s potential, environmental considerations, site selection, economic viability, policy implications, and partnerships. The document’s conclusion shares the next steps and needs identified by The Nature Conservancy (TNC) to continue growth toward a restorative aquaculture industry in Washington.

Aquaculture is a rapidly growing industry used for food and product production. When considering aquaculture’s projected growth, the challenge is minimizing its impacts while increasing benefits so that

farmers can grow seafood sustainably and equitably. Some aquaculture development has resulted in localized environmental damage. However, research shows that if deployed in suitable locations with sustainable practices and carefully selected species, aquaculture can yield numerous direct ecological benefits for ocean ecosystems and communities depending on them, including the potential for a net-positive environmental outcome. This approach to aquaculture practices is called *restorative aquaculture* (Figure 1; TNC 2021).

Seaweed aquaculture can be a direct food source, help produce sustainable products for an array of industries, benefit coastal communities, and contribute to ocean health (TNC 2021). Its products have a wide range of potential uses for human consumption

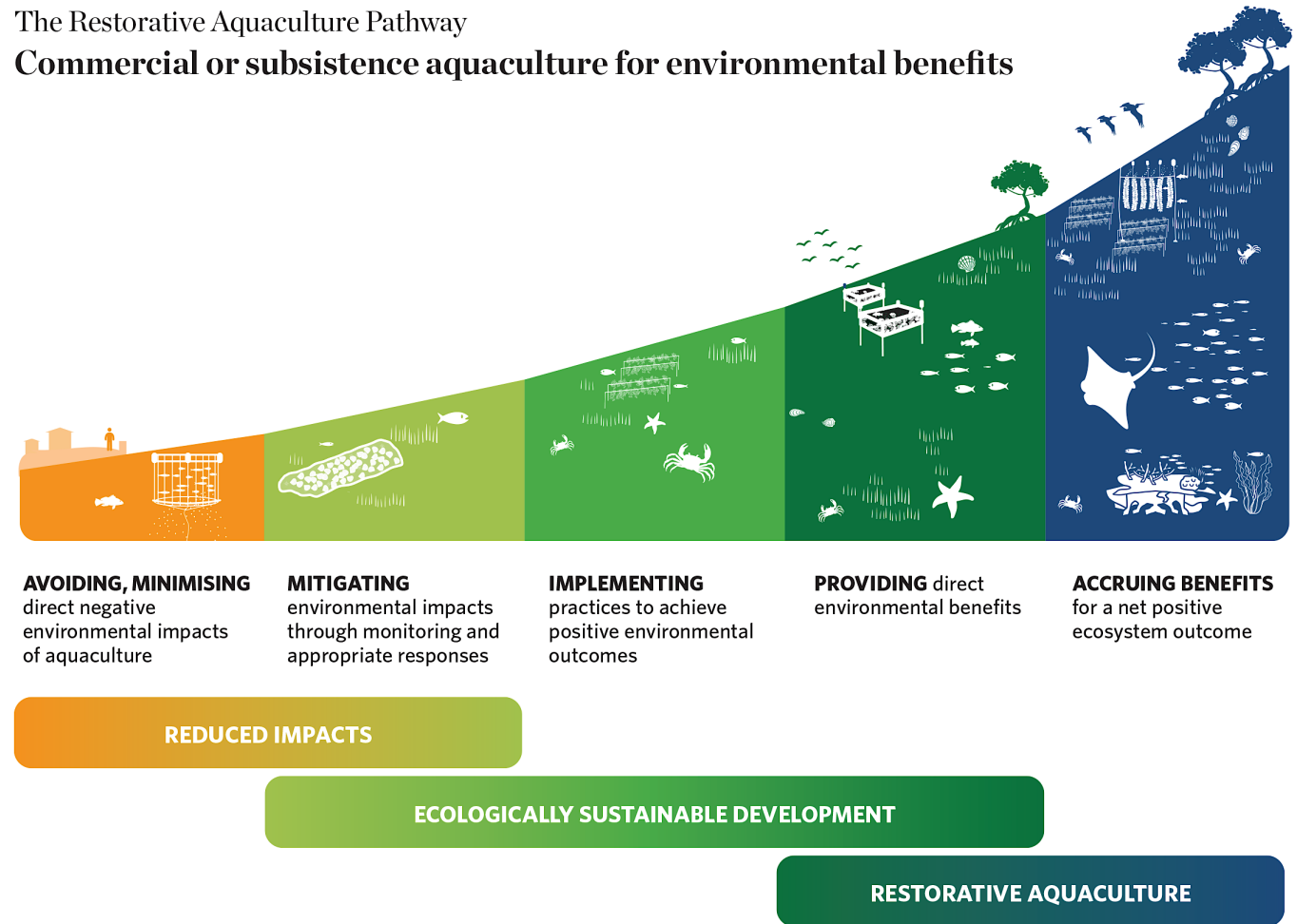


Figure 1. Restorative aquaculture yields net-positive ecosystem outcomes.

tion, cosmetics, pharmaceuticals, animal feed, fertilizers, biofuels, bioplastics, nutraceuticals, and chemicals (Piconi et al. 2020; McKinley Research Group 2021). Seaweed aquaculture can be sustainable as it requires no fresh water or added nourishment to grow and minimal land use for processing. It can further benefit the environment by providing water quality, habitat, and potentially, climate benefits (Gentry et al. 2020; Price et al. 2024).

Globally, seaweed aquaculture is a significant industry, producing over 36 million tons wet weight of farmed and harvested seaweed (FAO [Food and Agriculture Organization of the United Nations] 2024). Ninety-five percent of seaweed grown for commercial purposes includes species in four genera—*Saccharina*, *Gracilaria*, *Pyropia*, and *Undaria*—along with the broad category of eucheumatoids (Hatch Innovation Services 2022; World Bank 2023). Ninety-eight percent of seaweed is produced in East and Southwest Asia, with China (56%) and Indonesia (27%) as the top producers alongside well-established complementary industries, including the food and beverage industries and the hydrocolloid industry that produces thickeners for food and other products (World Bank 2023; FAO 2024). If identified markets emerge, the industry has the potential to grow an additional \$11.8 billion by 2030 (World Bank 2023). The industry has expanded recently due to a surge in interest, spreading to regions beyond Asia, including North America (FAO 2024). Sugar kelp (*Saccharina latissima*) is currently the leading seaweed farmed in the U.S., with most in-water seaweed aquaculture endeavors occurring in Maine and Alaska (Robidoux and Chadsey 2023).

An analysis by TNC and the U.S. National Oceanic and Atmospheric Administration (NOAA) identified the Pacific Northwest as one of the top marine ecoregions in North America where seaweed aquaculture could be environmentally beneficial, socially acceptable, and economically viable (Theuerkauf et al. 2019). Still, the Pacific Northwest seaweed farming industry, similar to many novel seaweed geographies, faces several challenges, including but not limited to a lack of established end markets, financ-

ing, farmer expertise, and public acceptance; uncertain policies and regulations; time-consuming permitting processes; and few region-specific environmental studies on the benefits and impacts ([Appendix A](#)).

The importance of seaweed to Pacific Northwest Tribes

The Pacific Northwest region is the ancestral territory of numerous Tribes and First Nations. As the original and continuing stewards of the region's land and water, Tribes and First Nations must be involved as co-managers of these resources. Given the region's already busy waterways, introducing a seaweed aquaculture industry in Washington state requires careful consideration of conflicts over use of marine space, as well as the Usual and Accustomed Fishing Areas (U&As) of Western Washington Treaty Tribes (Buckner et al. 2023). Thus, early relationship building and thoughtful collaboration with Washington Tribes are imperative for the emerging industry.

The Boldt Decision (*United States v. State of Washington* 1974) reaffirmed the treaty rights promised to Western Washington Tribes, recognizing the Tribes as co-managers of marine resources and securing rights to 50% of the allowable harvest from their U&As (NWIFC [Northwest Indian Fisheries Commission] 2014). Tribes play an important role in any marine activity permitting process, including authority via the U.S. Army Corps of Engineers (USACE) to state their opposition to activities that would interfere with their ability to exercise their treaty rights.

Seaweed is an integral part of the lifeblood of Pacific Northwest Tribes and serves as a critical part of their social, cultural, and spiritual existence. Historical uses and traditional stories are just a few of the indicators of the close relationship between seaweed-dependent coastal ecosystems and Pacific Northwest Tribal systems (Naar 2020). This relationship is exemplified by the *kelp highway*, which spans the Pacific Rim from Asia to South America and likely served as a beacon for the first human inhabitants of the Pacific Northwest (Erlandson et al. 2007). First Peoples are believed to have followed

the kelp highway to find new land and resources while “fishing, hunting, and sheltering among the kelp forests” (Naar 2020: B-2). Supporting diverse marine resources while providing habitat and primary production, kelp forests have “sustained and inspired traditional Indigenous lifeways across continents and over generations” (Naar 2020: B-1).

The Pacific Northwest’s bull kelp (*Nereocystis luetkeana*) is a staple of traditional subsistence knowledge and innovation and was used in fishing, hunting, food preparation and storage, toys, target practice, and musical instruments (Naar 2020). The Lummi, Samish, and other Straits Salish Tribal groups used reef net fishing, which allowed them to work with the tides and kelp-laden rocky reefs to trap salmon (Naar 2020). This technique was one of a few that continued after Euro-American settler colonialism (Lane 1973). As an important traditional food for Salish Sea First Nations and Tribes, Pacific herring roe is still harvested using kelp (Naar 2020). Bull kelp was used by the Quileute, Quinault, Makah, and other Tribes as fishing, anchor, and harpoon lines and by the Nuu-chah-nulth for storing deer suet and healing salves (Turner and Bell 1971; Turner 2001; Naar 2020). Kelp and other seaweeds were also used in medicinal practices (Turner 1995). These are just a few examples of the countless ways Pacific Northwest Tribes and Canadian First Nations utilized kelp and seaweeds.

Aside from physical uses, kelp holds symbolic and spiritual importance. Kelp is represented “in various Coast Salish myths and stories, where it represents the interdependence between indigenous peoples and the sea, the reciprocal ties of kinship between humans and supernatural beings, and the potential perils of marine livelihoods” (Naar 2020: B-2).

Many Tribes in the Pacific Northwest are interested in and/or have concerns over seaweed aquaculture. Some Tribes see seaweed aquaculture as a way to restore ecosystems while providing culturally relevant economic opportunities. For example, Native Conservancy (www.nativeconservancy.org/) is a Tribal nonprofit working with Alaska Natives to provide seaweed aquaculture training and technical as-

“When I hear the term seaweed aquaculture, I think about partnership with the land. I also think about how aquaculture has been in my veins for at least seven generations. ... For me, it’s just a natural piece of the culture, and [we are] just trying to blend the new science and the new methods with it.”

~ Loni Grinnell Greninger, Vice Chair, Jamestown S’Klallam Tribe (WSG 2023: 25:09)



Bull kelp (© Jenn Burt, Nature United)

sistance, incorporate Indigenous knowledge, restore kelp populations, and provide job diversification opportunities. They have also provided support to Tribal Nations interested in exploring seaweed aquaculture. They have set a 10-year goal of helping deploy 100 Native-owned kelp farms that can grow 30 million pounds of kelp for the benefit of both Native communities and the environment (Native Conservancy n.d.). Native Conservancy seeks to scale its work to benefit Alaska Native communities. Moreover, the nonprofit seeks to respond to the “gold rush” of eager seaweed permittees who have recently entered Alaska—a state relatively friendly to seaweed permitting—and to address concern over corporate privatization of ocean space. The organization has an Oceanback Initiative to support

Native farmers with start-up costs, permit fees, equipment, and training.

In addition to farms owned and run by Alaska Natives, other Indigenous seaweed farms exist in the Pacific Northwest, including joint Indigenous and private company collaborations in British Columbia. The private seaweed aquaculture company Cascadia Seaweed (www.cascadiaseaweed.com) is currently working with multiple First Nations via a variety of business structures. Their current Indigenous seaweed aquaculture partners are listed as Klahoose First Nation, Ahousaht First Nation, Tsehaht First Nation, Tsawout First Nation, Uchucklesaht Tribe Government, Gitxaala Nation, and Metlakatla First Nation. While Cascadia Seaweed is not Native-owned, they state that their primary goal, in operating in the traditional territories of First Nations peoples, is to “empower additional First Nations ownership of the activities along the seaweed value chain” (Cascadia Seaweed 2022).

The Ahousaht First Nation’s collaboration with Cascadia Seaweed is structured such that Cascadia Seaweed works with and pays fees to the Maaquusiis Hahoulthee Stewardship Society (MHSS), a business development service for the Ahousaht First Nation, to use and operate a kelp farm on one of their marine aquaculture leases near Tofino, Canada. MHSS paid for and owns the seaweed aquaculture equipment and provides boat rides to the farm for partners. Cascadia Seaweed has also engaged in research to assess the ecosystem services of the farm via habitat provisioning and has stated that they leave 10% of the kelp for traditional harvest (C Bates, pers. comm., 2022). MHSS first engaged in this collaboration because they were interested in diversifying beyond salmon aquaculture lease agreements and in testing the economic feasibility of seaweed aquaculture, though in a lower-risk structure than operating a seaweed farm independently (T Atleo, pers. comm., 2023).

While Tribally owned seaweed aquaculture farms exist in the greater Pacific Northwest, as well as private-Tribal collaborations, no Tribally owned seaweed farms are in Washington state. Washington Tribes have expressed interest in both the benefits

and impacts of a growing seaweed aquaculture industry in Washington waters. TNC worked with The Whitener Group, a Native-owned consulting group, that engaged with and interviewed Washington’s coastal Tribes to better understand local Indigenous perspectives of seaweed aquaculture. The Whitener Group spoke with 20 individuals from 14 Tribes.

These conversations (Whitener Group unpublished) revealed that many Tribal representatives were interested in seaweed aquaculture for the following reasons:

- the restorative benefits of growing kelp,
- its potential to contribute to kelp restoration,
- commercial and profit-driven interests,
- economic development and diversification, and
- job creation that fits well within the Tribe’s culture.

While some Tribal representatives were supportive of seaweed aquaculture, others had concerns over the potential impacts or had other priorities and interests in marine waters. Specific concerns brought up included the following:

- limited space in the water,
- siting issues (e.g., interactions with other types of aquacultures and/or fishing activities),
- a desire to avoid floating aquaculture,
- the lack of a seafood- or marine-based economic division within their Tribe,
- negative environmental impacts (e.g., potential impacts to wild fisheries),
- other potential impacts to Tribal U&As, and
- other economic interests.

In addition to this outreach, Washington Sea Grant (WSG) held an Indigenous Perspectives panel at their Washington Seaweed Symposium. This panel included representatives from the Jamestown S’Klallam Tribe, Skokomish Tribe, Squaxin Island Tribe, and Suquamish Tribe. While a variety of topics were discussed, a primary area of consensus and advice from the Tribal panel was to encourage early collaboration and deep relationship building with Tribes before, during, and after any permitting for seaweed aquaculture (WSG 2023).

Seaweeds of Washington

The following overview of wild native seaweeds in Washington state is important for contextualizing how the aquaculture industry could best develop and how it could negatively and/or positively affect wild species, communities, cultures, and the environment.

Washington's coast is home to over 600 species of seaweeds, macroscopic plants, and protists that include red algae (phylum Rhodophyta), green algae (phylum Chlorophyta), and brown algae (phylum Phaeophyta). Among the many seaweeds in the state, kelps are currently thought to hold the most potential for aquaculture. The term *kelp* encompasses a group of large brown seaweeds from the order Laminariales. There are 22 species of kelp with three different morphologies: Prostrate kelp is the most common type of kelp and forms thick understories close to the seafloor (Calloway et al. 2020). Stipitate kelp forms a subcanopy in the water column, and floating kelp creates large surface canopies (Calloway et al. 2020). Kelps, especially large floating species like bull kelp and giant kelp (*Macrocystis tenuifolia*; formally called *M. pyrifera* or *M. integrifolia*), are known to provide important habitat for many species. Kelp forests are critical for protecting endangered species that use kelp as refuges, feeding areas, and nursery grounds; additionally, many species that rely on kelp forests are part of the food web for other species, such as shore birds and Southern Resident killer whales (a distinct population of *Orcinus orca*; Calloway et al. 2020). Along Washington's coasts, giant kelp can be found along the northern Pacific coast of Washington and the western Strait of Juan de Fuca. Bull kelp can be found along the northern Pacific coast, the Strait of Juan de Fuca, and into Puget Sound (Berry et al. 2023).

Kelp species can be vulnerable to environmental changes, including increases in water temperature, ecosystem changes like declines in predator populations that feed on grazers (e.g., urchins, crabs, and snails), and sedimentation and pollution from coastal development, agriculture, and/or forestry practices (Palmer-McGee n.d.; Berry et al. 2021; NOAA 2022). The Puget Sound Partnership (2024) identified the

floating kelp bed area as an indicator for evaluating progress toward Puget Sound recovery per the *beach and marine vegetation* vital sign, aiming to restore functioning habitat. The Kelp Forest Monitoring Alliance of Washington State published a summary report to inform the *floating kelp bed area* vital sign in 2023 and indicated that, in comparison to baseline data, the overall floating kelp area is "getting worse" (Puget Sound Partnership 2024). However, monitoring results have shown that floating kelp status varies by region: Washington's northern Pacific coast and the Strait of Juan de Fuca have relatively stable kelp beds. The San Juan Islands and the Saratoga and Whidbey Basins have noted concerns of decline. Substantial declines have been documented in South Puget Sound (Berry et al. 2023). Other areas, such as North Puget Sound and Admiralty Inlet, were too data-limited to assess. Each region has site-level exceptions to the long-term trends and patterns (Berry et al. 2023).

In contrast to floating kelp, understory kelp populations (e.g., sugar kelp) have been studied less due to the difficulty of underwater monitoring. The *Puget Sound Kelp Conservation and Recovery Plan* (the Kelp Plan) called out a need to expand understory species research and learn how collaborative monitoring efforts—such as those led by the Washington State Department of Natural Resources (DNR)—are needed to learn about these diverse and ecologically important species (Calloway et al. 2020; Christiaen 2020).

Wild kelp recovery, discussed in the next section, is critical to protecting ecosystem health and supporting Tribal first foods and cultures. Restoration needs and challenges present a unique opportunity for seaweed farmers to partner with researchers to advance both restorative aquaculture and the conservation of native kelp beds.

Puget Sound kelp restoration and research endeavors

Puget Sound Restoration Fund (PSRF), DNR, NOAA, Marine Agronomics, and the Northwest Straits Commission (NWSC) came together to lead the development of the Kelp Plan (Calloway et al. 2020). This



Lime Kiln Point State Park, Friday Harbor, WA (© Morgan Heim)

plan “provides a framework for coordinated research and management actions to protect these fundamental and iconic kelp species from a suite of global and local stressors” (Calloway et al. 2020: 1). It highlights the importance of “interagency coordination; communication between researchers and managers; and funding to support research, monitoring, education, outreach, implementation, and enforcement” (Calloway et al. 2020: 4). The Kelp Plan’s strategic goals and associated actions include “form[ing] an interagency workgroup to review the kelp aquaculture permitting process and develop best management practices, such as cultivating native species, avoiding the spread of pathogens, and avoiding the use of harmful pesticides and other chemicals” (Calloway et al. 2020: 30). Regarding the potential contribution of aquaculture to kelp recovery, the plan states that while seaweed aquaculture may provide benefits, it should not be used as a replacement for naturally occurring populations, nor should it negatively impact or displace native seaweeds.

In response to recent losses in kelp forests and a need to proactively identify actions to improve the resilience of kelp forests and eelgrass meadows, the Washington State legislature passed Senate Bill 5619, which created a law titled “Native Kelp Forest and Eelgrass Meadow Health and Conservation Plan—Reports” (RCW 79.135.440; 2025), effective in 2022. It directed DNR to develop the eponymous plan. This effort aims to develop prioritization, monitoring, and engagement plans to “conserve and restore at least 10,000 acres of native kelp forests and eelgrass meadows by 2040.” The law says that the plan must “proactively and systematically address” several actions, including “identify[ing] research necessary to analyze and assess potential ecological, environmental, and community benefits of aquaculture of native species” (RCW 79.135.440.2.a.ii). Through the Kelp Plan and this law, state agencies have interests in contributing to best practices, preventing negative impacts, and considering the benefits of kelp aquaculture for native kelp recovery.

To address policy gaps identified in the Kelp Plan, The Pew Charitable Trusts provided support to the NWSC to form an interagency Kelp Policy Advisory Group to increase collaboration and information sharing, as well as address policy gaps. From 2021 to 2023, the Kelp Policy Advisory Group convened and engaged over 100 kelp practitioners, stakeholders, Tribes, and partners to develop 11 recommendations to improve kelp recovery and protection. Recommendations included actions ranging from the development of kelp fact sheets and agency guidance documents to training programs, lists of science and research needs, and the establishment of a long-term interagency kelp advisory group (Oster et al. 2023).

In July 2021, more than 40 partner organizations and Tribes joined PSRF on a Kelp Expedition in the southern Salish Sea. The journey allowed stakeholders to see kelp forests up close, better understand the Kelp Plan's goals, and inspire collaboration, research, and knowledge transfer. This project encapsulated some of the many efforts underway to monitor and restore kelp forests, including kayak-based monitoring and mapping by Marine Resource Committees, academic and agency research activities, Tribally led restoration projects, and much more. To share these incredible collaborations and efforts, PSRF developed a story map (Garfield 2021) about the journey, the importance of kelp forests to the region, and ways each person can take action to support recovery.

Efforts are expanding to protect and restore kelp beds throughout Washington state. PSRF is developing practices to recover bull kelp forests in several locations, testing different methods of propagating and growing kelp, and exploring the ability of kelp restoration sites to contribute to recovery through seed dispersal and natural recruitment. These efforts include partnering with the Jamestown S'Klallam Tribe to survey kelp populations and build a seed bank of kelp species, such as three-ribbed kelp (*Cymathoere triplicata*), winged kelp (aka ribbon kelp; *Alaria marginata*), and bull kelp (North-

west Treaty Tribes 2022). The seed bank will preserve kelp gametophytes for future restoration efforts (PSRF n.d.).

Overview of Washington's seaweed aquaculture industry

In the 1970s, DNR investigated the commercial cultivation of a Japanese red algae, *Pyropia* (aka nori), due to the ideal year-round growing conditions in Puget Sound and an increasing demand for nori sheets for sushi restaurants (Mumford 1990). After commissioning a study to see if the U.S. could successfully enter the *Pyropia* market, hiring a Japanese consultant, and determining that the *Pyropia* did not have the potential to become invasive, DNR and the University of Washington successfully piloted growing *Pyropia* on floating rafts from 1982 to 1983 (Bergdahl 1990; Kim et al. 2019). This effort led to the development of the Pacific Northwest Nori Growers Association and three new seaweed-growing businesses (Kim et al. 2019). However, industry progress was halted by political and social resistance, largely due to NIMBY (not in my backyard) perspectives among shoreline homeowners (Kim et al. 2019).

Interest in seaweed farming in Washington has emerged again. Starting in 2019, research and partnerships grew around seaweed cultivation and its benefits to people and the environment. These partnerships, coupled with public interest, led organizations like WSG to host workshops, trainings, conferences, and other collaboration opportunities for Washington's emerging seaweed community.

In January 2025, TNC received a response from a public records request they submitted to DNR to determine how many seaweed farm leases, farm applications, and possible future applicants were held in the DNR database. The database contained three current tenants/licensees, three applicants, and seven interested parties that had reached out to DNR at some point (TNC unpublished).

Washington seaweed aquaculture's roots in research

The active kelp research and restoration community in Washington presents a unique opportunity for seaweed farmers to collaborate or contribute to restoration and research. In fact, the state's first in-water kelp farm, Blue Dot Sea Farms (bluedotseafarms.com), spans 5 acres and is located near the north end of Hood Canal. The farm was established in 2015 as a scientific investigation into the potential of cultivated kelp to buffer surrounding seawater against ocean acidification and to improve water quality for shellfish aquaculture (Peabody et al.

2020). Since then, the farm has produced sugar kelp commercially and is continuing to investigate the ecosystem benefits of oyster and kelp co-culture. Blue Dot has engaged in many research collaborations, including studies on the use of carbon-fiber cables for aquaculture, the carbon and nutrient uptake of kelp, and the use of farmed kelp for ethanol, fertilizers, and fish feeds. Currently, the farm is working with the University of Washington Materials Science and Engineering program to explore the use of kelp for bioplastics. The farm is also exploring the potential to transition from growing sugar kelp to bull kelp for both restoration and food purposes (J Davis, pers. comm., 2025). This interest in research partnerships has extended to the next wave of current and prospective kelp farmers in Washington.

Lummi Island SeaGreens (lummiislandseagreens.com), located in Legoe Bay, was the first farm in Washington to be permitted and authorized as a commercial operation from the start. The farm utilizes existing reef-net fishing infrastructure to grow sugar kelp on lines, providing diversification opportunities for fisheries. The farm's research interests are currently focused on chemical and nutritional analyses of the kelp and pressed kelp fluids, building important information to inform potential markets (R Starks, pers. comm., 2024).

A 10-acre farm, Pacific Sea Farms (www.pacificseafarms.com), was located off the southwest shore of Vashon Island. The farm completed permitting and leasing for commercial operations in 2024. While the farm is no longer in operation, it was a co-culture operation, growing sugar kelp and oysters, and other shellfish in a vertical system, with kelp grown on lines alongside shellfish in cages.



Above: Blue Dot Sea Farms (© Joth Davis); below: Lummi Island SeaGreens (© Riley Starks)

When in operation, Pacific Sea Farms was open to discussing pathways to a DNR partnership to measure light radiance beneath the kelp canopy at different growth stages and understand any impacts on benthic native aquatic vegetation (NAV) from shading. The farm was also considering partnerships with researchers and local community groups to conduct studies on kelp genetics, fish and invertebrate interactions, and the farm's impact on local waves, currents, and water quality (M Spranger, pers. comm., 2024). The farm was also working with Vashon Nature Center to survey birds both at the farm and nearby reference sites (M Spranger, pers. comm., 2024).

Another Vashon Island kelp farm proposal, Vashon Kelp Forest (www.vashonkelpforest.com), has received permits for a 10-acre site in Colvos Passage and would like to work with DNR to obtain a lease and proceed with kelp cultivation. The farm aims to cultivate bull kelp for both harvest and restoration, while providing education opportunities and local jobs in the community.

The farm seeks to partner with nongovernmental organizations (NGOs) and researchers to better understand the ecological function of farmed kelp versus nearby natural kelp beds (M Kolins, pers. comm., 2024). Additionally, the Vashon Kelp Forest project would like to contribute to restoration by leaving a portion of their farm unharvested, with the goal of allowing mature kelp to reproduce and replenish local wild kelp beds, as well as

provide habitat for marine species. Key to this approach would be ensuring that the genetic diversity of the kelp seed outplanted by Vashon Kelp Forest matched that of nearby wild populations. However, leaving commercially farmed kelp in the water and allowing reproductive material to develop is currently not allowed (DNR 2024b).



Surveying in the upper canopy of a forest of giant kelp and bull kelp, Asilomar Park in California (© Richard Herrmann)

The above examples of Washingtonians' interests and the state agencies' commitments to kelp conservation and restoration highlight the role that kelp farming has and can play in supporting these efforts. Many of the permitted seaweed farms have taken the initiative to support research efforts, and prospective seaweed farmers continue to show interest in pairing commercial operations with contributions to restoration and research.

The emerging seaweed aquaculture community

As interest in seaweed aquaculture has grown, WSG has fostered the development of a community for the emergent industry. In 2020, WSG worked with a grassroots network of seaweed community members (including Hood Canal Mariculture [currently operating as Blue Dot Sea Farms], PSRF, NOAA, and the Veterans Conservation Corps) to host Seaweed Farming Intensive Training, a three-day event for prospective seaweed farmers. The 70 participants learned about topics such as farm siting, aquaculture permitting, the ecology of local seaweeds, seaweed product marketing, and business management (WSG News Blog 2020). The groundswell of participants' enthusiasm for continued engagement and learning prompted WSG to establish the Washington Seaweed Collaborative (WSC). Today, this community of practice has over 400 members that include representatives from Tribes, government agencies, ocean farmers, scientists, and restoration practitioners.

The WSC also has an advisory committee, and its charter outlines the following goals:

- Convene seaweed constituents.
- Educate prospective and active seaweed farmers, Tribal communities, government officials, and the public about environmentally responsible seaweed cultivation and the potential for seaweed as a marketable commodity.
- Facilitate connections and collaborations.
- Collaborate with authorities to provide guidance for interested parties navigating the permitting and leasing process and to facilitate communication and consultation with affected Tribal governments.

The WSC also coordinated the first Washington Seaweed Knowledge Symposium held on December 8, 2022, bringing in experts to cover topics such as seaweed and water quality, kelp conservation and recovery, potential habitat effects, seaweed genetics, multi-trophic aquaculture opportunities, Indigenous perspectives, state agency perspectives, and public perceptions (WSC 2022). Recordings of the talks and discussions from the event can be found on the WSC website (waseaweedcollaborative.org/washington-seaweed-co-agenda).



Section 2: Environmental considerations & site selection for open-water-based seaweed aquaculture

Key takeaways

- The potential ecosystem benefits of seaweed aquaculture include improved water quality, habitat and food provisioning, and potential climate benefits.
- Significant in-water carbon sequestration from seaweed aquaculture in Washington is unlikely. However, the downstream benefits of product pathways could result in reduced carbon emissions.
- Thoughtful siting and best practices are necessary to prevent negative impacts from seaweed aquaculture activities and infrastructure.
- Site selection should focus on minimizing environmental harm and impacts to sensitive habitats. Site selection can also be used to place seaweed where it is most ecologically beneficial.

Environmental benefits and impacts

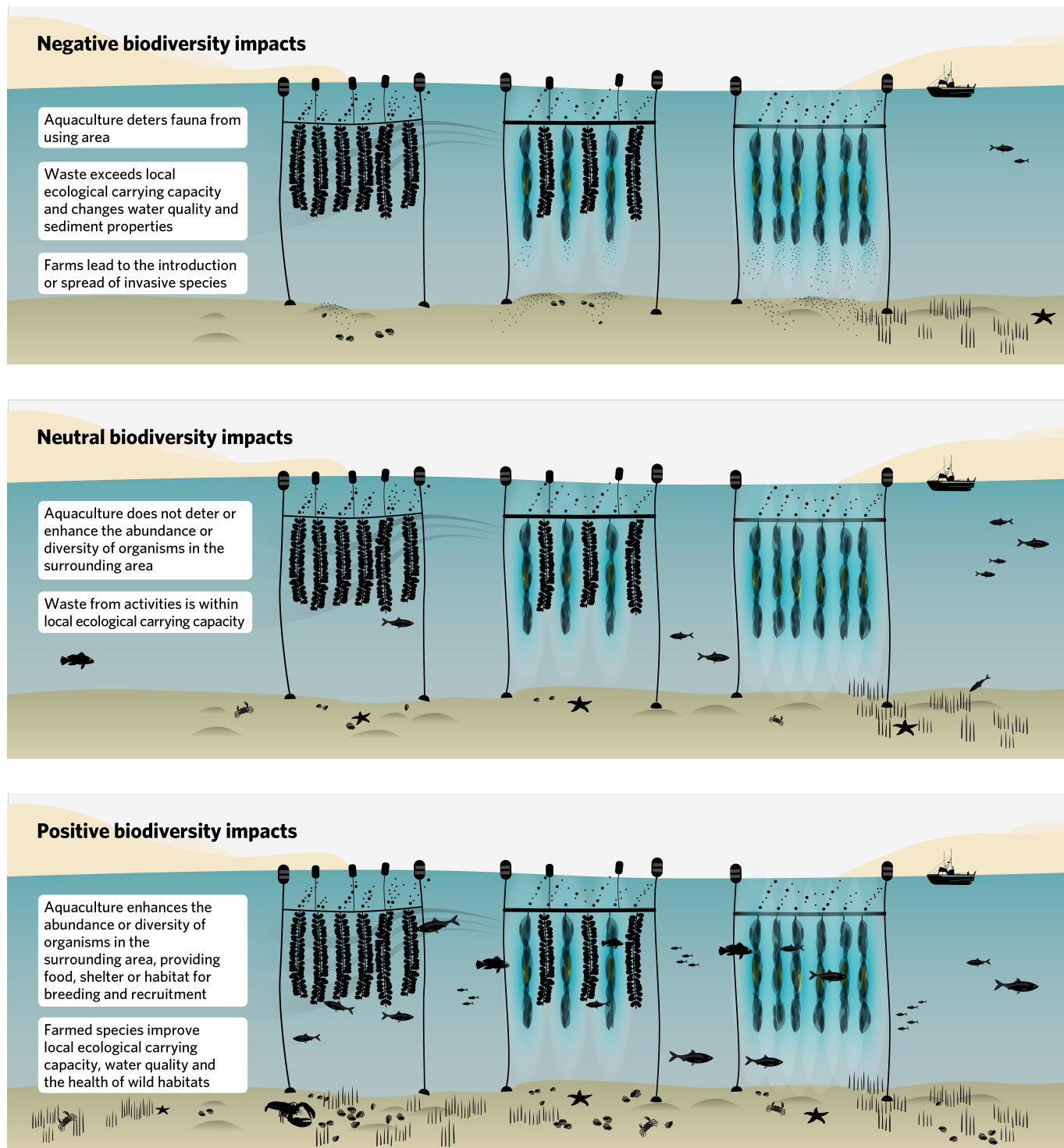


Figure 2. The negative, neutral, and positive biodiversity impacts of seaweed aquaculture.

Marine aquaculture has the potential to have positive, negative, and neutral effects on the environment (Figure 2), and evaluation is critical to planning and designing sustainable farms, building public

support for seaweed farming, and informing the industry's regulatory requirements (Gentry et al. 2020; Considine et al. 2023). Due to the nascent industry on the West Coast, additional research is needed to

ensure farms are managed in ways that have a neutral or positive effect on the environment. This section discusses the potential benefits and impacts of seaweed farming on water quality, climate, habitats, genetics, and biosecurity.

Water quality

Of all the ecosystem services provided by seaweeds, the most widely studied and discussed in the literature are the benefits to water quality from nutrient absorption. Growing seaweed in marine waters does not require fertilizers or any other additives but can instead improve surrounding water quality by absorbing excess nutrients and toxins, providing oxygen, and buffering the impacts of ocean acidification locally. Cultivating seaweed for commercial markets or bioremediation purposes has the potential to deliver such co-benefits.

Nutrients

Through photosynthesis, seaweeds gain the energy needed to absorb nutrients from water to build cell structures and increase their biomass, which is called *nutrient assimilation* (Pederson and Borum 1997). Nutrients, including nitrogen and phosphorus, enter the ocean through point and nonpoint sources by way of natural inputs (e.g., soil erosion) and anthropogenic inputs (e.g., sewage overflow, excess fertilizers, and atmospheric deposition). When nitrogen and phosphorus levels rise above what is needed for primary production, eutrophication occurs and can lead to impacts such as harmful algal blooms and oxygen depletion, including hypoxia and anoxia (Rabalais et al. 2009).

In eutrophic areas, farmed seaweed can contribute to improved water quality by assimilating nutrients from the water column that are subsequently removed from the water body during harvest, potentially decreasing the impacts of excess nutrients in the ecosystem (Seghetta et al. 2016; Xiao et al. 2017; Petersen et al. 2019; Jiang et al. 2020; Racine et al. 2021). Dr. Thierry Chopin (2023), an acclaimed scientist of seaweed and integrated multi-trophic aquaculture, notably called seaweeds “excellent nutrient scrubbers.” Seaweeds are so effective in their nutrient removal capabilities that in nutrient-limited areas or areas with interest in large-scale seaweed

production, the nutrient availability should be measured and used to determine appropriate farm size and seaweed densities (Roleda and Hurd 2019).

Organic and inorganic contaminants

Seaweeds can accumulate and concentrate heavy metal toxins such as arsenic, cadmium, lead, and mercury from surrounding sediment and the water column (Wells et al. 2017; Hahn et al. 2022; Shaughnessy et al. 2023b). The level of heavy metals in a given seaweed sample depends on many factors, including the species and surrounding pollutant levels, as well as the local water temperature, pH, and salinity (Shaughnessy et al. 2023b). Additional studies are needed to better understand how bioaccessible these metals are when processed in digestive systems to ascertain their potential impact on human health when consumed (Wells et al. 2017).

Seaweeds can also accumulate polycyclic aromatic hydrocarbons (PAHs), polychlorinated-dibenzofurans (PCDFs), polybrominated diphenyl ethers (PBDEs), pesticides, and other emerging contaminants like per- and polyfluoroalkyl substances (PFAS), pharmaceuticals, and personal care products present in water (Hahn et al. 2022). In a study conducted by Hahn et al. (2022) to inform the harvest of commonly collected edible seaweeds in the Salish Sea, PCBs, PAH (specifically, benzo[a]pyrene [BaP]), cadmium, mercury, and lead were observed in concentrations above international limits. However, contaminant concentrations varied by site, and a majority of the concentrations were below international limits (Hahn et al. 2022).

Given seaweed’s natural ability to accumulate contaminants, it is important to consider siting and regulatory requirements when using seaweed for human consumption or other products that could be sensitive to metals. See the “[product safety regulations](#)” section for more on the regulatory aspects of contaminants.

Bioremediation

Strategically cultivating seaweeds to capture excess nutrients or toxins is called *bioremediation*. More specifically, the use of seaweed for the removal of inorganic nutrients is often referred to as

nutrient bioextraction (Kim et al. 2014; Rose et al. 2015). The nutrient assimilation capabilities of seaweeds vary by species, farm structure, and abiotic factors, such as nutrient salinity, temperature, and light, making it challenging to precisely estimate nutrient removal capacity (Kim et al. 2014; Umanzor and Stephens 2023). A recent study estimated that farmed sugar kelp (an aquaculture species of interest in Washington) removed between $19.2 (\pm 4.8)$ and $176 (\pm 7.7)$ kg N ha⁻¹ in the Western Gulf of Maine (Grebe et al. 2021).

Puget Sound's water quality has been degrading since settler colonialism due to increased industrialization and agricultural activities. Depending on the scale and level of nutrients able to be removed, cultivating seaweed in polluted areas could be a cost-effective nutrient management tool for local watersheds to add to existing efforts for curbing pollution upstream (Kimbrough et al. 2008; Evans and Edwards 2011; Shams El-Din et al. 2014; Racine et al. 2021). While the Washington-specific bioextraction potential of seaweeds has not been investigated, this area of study could be explored and, if promising, could support the consideration of aquaculture for a nutrient credit program or water-quality trading program to help manage discharge from point sources such as wastewater treatment plants.

Marine plastic pollution

Public concerns over aquaculture-related marine plastic pollution arise due to current practices that rely on various plastics, including equipment like ropes, buoys, and plastic mesh, as well as packaging materials for supplies and final products (Huntington 2019; Sandra et al. 2019; Skirtun et al. 2022). Seaweed aquaculture often uses plastic ropes, buoys, and ties. Generally, the effects in the U.S. of aquaculture-related plastic and microplastic pollution have not been well quantified and have been highly debated (Schoof and DeNike 2017). However, some stakeholders have raised concerns; shellfish aquaculture leases have been legally contested in the past, in part over concerns about potential plastic pollution (Nichols 2017).

Because it is in an early stage and historically open to research collaborations, Washington's seaweed

industry has an opportunity to help test alternative or biodegradable materials like buoys made of mycelium (Bell unpublished) and/or lines made of recycled carbon fiber. Washington's Blue Dot Sea Farms is currently working with a Port Angeles-based company, the Composite Recycling Technology Center, on the use of recycled carbon fiber in their seaweed and shellfish farm, with initial results showing potential for greater yield due to increased planting density, longer use and versatility in the water, and reduced labor costs (Kroman 2024).

While nonplastic products are being trialed and developed, an interim solution for current and potential seaweed growers is to continue investing in higher-quality plastic gear rather than Styrofoam, low-quality plastics, or other materials that break down quickly in the marine environment. The industry could also work to increase knowledge sharing on waste management and consider recycling options (Skirtun et al. 2022). At the policy level, governments can help mitigate accidental pollution by implementing regulations and minimum standards for the type of gear and supplies used by aquaculture farms (Hipólito et al. 2020; Skirtun et al. 2022).

Climate

Washington's waters are experiencing the effects of climate change, including warming ocean temperatures, changes in precipitation patterns, reduced snowpack, and ocean acidification, all of which directly affect ocean productivity and biodiversity. The potential climate benefits of seaweed aquaculture may include in-water benefits, such as carbon absorption and storage, and supply chain benefits, such as carbon emissions that could be avoided if seaweed-based materials have a lower footprint than conventional alternatives.



Blue Dot Sea Farms (© Joth Davis)

In-water benefits

Carbon absorption and storage

The carbon storage potential of seaweed farms globally is a novel and emerging field. Wild seaweeds, especially kelp, grow quickly, converting carbon dioxide (CO₂) into energy and biomass. However, the carbon storage potential depends greatly on the percentage of biomass that becomes mineralized versus buried in nearby sediments or transported to the deep sea (Krause-Jensen and Duarte 2016; Duarte et al. 2025). As the majority of farmed seaweed is removed from the water, only seaweed fragments that break off the growlines—thus sinking to the seafloor or nearby blue carbon habitats and becoming buried—could be stored for any meaningful period. This process is highly site-dependent, and any claims about sequestration should be verified by rigorous third-party verification and on-site measurements, especially if they are the basis for issuing carbon credits.

The most significant study to date analyzed sediment accumulation rates and organic carbon densities below 20 seaweed farms from 11 countries around the world. The study (Duarte et al. 2025) indicated that the thickness of soil layers and carbon stocks accumulated below the farms increased with farm age and yield when farms were placed over undisturbed depositional environments (e.g., soft sediments). At these sites, sediment cores showed a large variation between farms with an average of 1.87 tCO₂e ha⁻¹ yr⁻¹, with a maximum of 8.99 tCO₂e ha⁻¹ yr⁻¹. One of the study's primary conclusions was that climate mitigation should be considered a co-benefit, though it is a relatively modest benefit. While sediment accumulation could have positive benefits for carbon storage, permitting and leasing agencies may also want to further understand the benefits and impacts of this organic material on benthic infaunal communities.

To increase the contribution of seaweed farming to carbon storage, some prospective farmers have considered purposely sinking farmed kelp in the

deep sea. However, concerns about this concept have been growing among the scientific and conservation communities, including the effectiveness of the practice and the potential for unknown detrimental impacts on the deep-sea ecosystem (Webb et al. 2021; Ocean Visions and Monterey Bay Aquarium Research Institute 2022; Ricart et al. 2022).

A study from TNC and Bain and Company (2023) pulled in data from the preprint version of the Duarte et al. (2025) research mentioned above. This study analyzed the potential of carbon credit opportunities for farmers and conservation. Using high-end averages from tropical ($5 \text{ tCO}_2\text{e ha}^{-1} \text{ yr}^{-1}$) and temperate ($2 \text{ tCO}_2\text{e ha}^{-1} \text{ yr}^{-1}$) regions, the study input this data into a carbon crediting model that included carbon market considerations, such as additionality and discounts. This analysis found that due to the lower levels of storage, current carbon crediting prices would not provide sufficient income for behavior change. To motivate change and make carbon financing minimally attractive, voluntary carbon prices would need to be \$300–\$500 per ton. Alternatively, additional scientific data would need to be identified that showed higher levels of carbon sequestration (TNC and Bain and Company 2023).

Further research is needed to gather localized data on carbon burial and quantify carbon pathways (beyond below-farm burial) to refine the sequestration potential of seaweed aquaculture. While the carbon sequestration services of kelp farming are likely low, other ecosystem services, such as improved water quality and habitat benefits, could potentially be an avenue for bolstering the value of seaweed farming beyond carbon credits via markets that provide payments for ecosystem services, such as biodiversity or sustainable development.

SciTech Environmental Consulting and TNC (2023) created a global seaweed carbon and nutrient model that allows a seaweed user to select their marine ecoregion, input their seaweed farm information, and list their seaweed products. Users can select the Oregon, Washington, Vancouver Coast and Shelf marine ecoregion, input current or potential seaweed farms and products, and receive estimates of carbon sequestration potential, nutrient removal,

and potential carbon emissions avoided due to seaweed products produced. It should be noted that these model outputs are theoretical, and the accuracy increases when local data is used as an input.

Ocean acidification

Through photosynthesis, seaweed absorbs CO_2 and produces oxygen, which has the potential to raise the pH of surrounding seawater and create a “halo” of more favorable conditions for calcifying organisms like shellfish that are vulnerable to ocean acidification (Xiao et al. 2021). Co-culturing shellfish with seaweed may help mitigate coastal acidification impacts on shellfish aquaculture by providing this localized buffering effect. Such an effect is particularly pertinent to the Pacific Northwest and its people due to coastal upwelling and climate change, as the area is especially vulnerable to ocean acidification, which can negatively impact the calcification of marine organisms like oysters and mussels (Barton et al. 2015). Indigenous people have harvested shellfish on Pacific Northwest tidelands for thousands of years, and Washington state is currently the largest producer of farmed clams and oysters in the Pacific Northwest (Barton et al. 2015). The regional shellfish industry is socioeconomically and culturally sensitive to changing ocean conditions, including seasonal coastal upwelling of CO_2 -rich waters that has negatively impacted Washington’s oyster aquaculture industry (Gazeau et al. 2007; Barton et al. 2015; Katz 2020).

As mentioned above, seaweed can provide a localized halo effect of ocean acidification buffering, which is one of its ecosystem services. That said, site-specific factors like current velocity, kelp density, and farm size will greatly determine the extent of a farm’s effect on seawater chemistry (Rensel 2015), and some studies have had mixed results (Fernández et al. 2019; Han et al. 2020; Xiao et al. 2021; Price et al. 2024), underscoring the need for localized research. A research endeavor at Washington’s Blue Dot Sea Farms, in collaboration with WSG, PSRF, and the University of Washington, studied the seawater chemistry effects of co-culturing kelp and shellfish. While the sensors used in the study did not detect any differences in seawater

chemistry inside versus outside of the farm, these findings were likely due to high current speeds at the study site and a larger influence of plankton blooms that coincided with the time frame of the project (Peabody et al. 2020). Anecdotal evidence showed that shellfish (Pacific oysters [*Crassostrea gigas*], Olympia oysters [*Ostrea lurida*], and bay mussels) grown alongside kelp had stronger shells, and the Pacific and Olympia oysters had higher growth rates (Peabody et al. 2020).

Wave attenuation and other coastal protection

As a coastal erosion buffer, wild and farmed seaweeds can change the nearshore environment by dampening wave energy and providing protection, depending on the scale of the farm equipment (Duarte et al. 2017). Attenuating wave energy can protect coastlines against erosion and coastal storms. The kelp farms' wave attenuation capabilities could be enhanced by the following (Zhu et al. 2021):

- situating longlines perpendicular to incoming waves,
- expanding the number of longlines and consequently enlarging the overall farm size,
- locating farms in shallow water and in a higher position in the water column,
- growing densely packed kelp, and
- selecting species that tend to grow wider and longer blades.

However, additional studies specific to Washington waters, particularly coastal regions that need wave

attenuation benefits, should be conducted to assess the feasibility of this service.

Supply chain carbon benefits

Seaweed farming has some of the lowest greenhouse gas emissions within the aquaculture sector (Hall et al. 2011). To further reduce net greenhouse gas emissions, farmers may consider choosing an appropriate farm location, choosing suitable seaweed species, optimizing farm area to maximize yields, reducing plastic and fuel use on the farm, reducing energy use for processing and transport, and developing climate-friendly products (Pechsiri et al. 2016; Jones et al. 2022; Troell et al. 2022).

In many cases, processing is the most energy-intensive aspect of farming, especially in temperate environments, due to the infrastructure needed to dry seaweed (Jones et al. 2022). Farming operations should pay attention to the energy sources used for cultivation to minimize the overall greenhouse gas emissions generated (Jones et al. 2022). Farmers could also investigate opportunities to incorporate renewable energy sources into their farming infrastructure, as demonstrated by a partnership between the Jamestown S'Klallam Tribe and the Pacific Northwest National Laboratory to conduct an aquaculture energy assessment (PNNL n.d.).

When kelp replaces more energy-intensive materials, carbon emissions can be avoided during the creation of different products, such as animal feed, bio-fuels, biomaterials, and fertilizer (Duarte et al. 2017;



Bull kelp along the shoreline (© Jenn Burt, Nature United)

Alleway et al. 2022; Troell et al. 2022). A recent analysis conducted by TNC and Bain and Company (2023) identified biostimulants and bioplastics as the most promising seaweed products and markets to realistically grow the industry in novel locations in the next five to 10 years, with the following added benefits: increased soil health, plastic reduction, and lower carbon emissions. The study estimated that for every 1 million tons of seaweed produced for biostimulants, 0.25 Mt of CO₂ emissions could be avoided (TNC and Bain and Company 2023).

Some studies have also shown that feed quality could be improved and methane emissions reduced by adding certain species of seaweed to the diets of livestock, such as cows and sheep (Li et al. 2016; Roque et al. 2021). Bioactive elements in seaweeds have been shown to suppress archaea and protozoa and inhibit methane production (Price et al. 2024). For example, a tropical red seaweed called red sea plume (aka limu kohu; *Asparagopsis taxiformis*) was found to reduce up to 98% of cattle's methane production (Camer-Pesci et al. 2023). Another red seaweed from Maine, called Irish moss (aka sea moss; *Chondrus crispus*), was found to reduce cattle's methane production by 13.9% while maintaining milk production and quality (Reyes et al. 2023). The ability of temperate kelp species to provide similar methane reduction benefits is less well-known. In Europe, studies showed that adding sugar kelp (the primary species currently cultivated in Washington) to cattle diets has not been as effective (Muizelaar et al. 2023; Thorsteinsson et al. 2023). A recent report by Bigelow Laboratory for Ocean Sciences confirmed that seaweed has promising results for methane reduction, but more research is necessary to evaluate how effective each of the different seaweed species is at reducing methane production under various conditions (Price et al. 2024).

Habitat

Habitat provisioning

Seaweed aquaculture has the potential to provide positive benefits to ecosystems through habitat provisioning. Floating seaweed farms and their associated infrastructure can enhance foraging,

spawning, and refuge opportunities for fish and macroinvertebrates, leading to higher species abundance and richness than reference sites (Forbes et al. 2022; Theuerkauf et al. 2022). Detritus from seaweed farms can also support increases in benthic infauna abundance and diversity (Visch et al. 2020). However, there are differences between natural kelp forests and farm settings; a farm's local conditions and practices can significantly influence the degree of positive benefits (Forbes et al. 2022). For example, foraging opportunities may peak when biofouling occurs, and seaweed is often harvested before fouling organisms settle to produce high-quality products (Forbes et al. 2022).

Research on the benefits and impacts of farmed seaweed for habitat and species biodiversity is minimal for temperate environments, and the potential habitat services provided by seaweed aquaculture will depend on local conditions, species present, and a range of farm management practices (Considine et al. 2023). For example, while the floating structure and food availability provided by natural kelp beds can serve as an important habitat for salmon in Washington waters (Shaffer et al. 2020), it would be crucial to understand salmon migratory pathways and potential overlaps with kelp farm locations, as well as potential interactions from maintenance and harvest activities. Additionally, juvenile rockfish rely on kelp forests for nursery habitat, making kelp essential for rockfish recovery (Calloway 2020), but local studies are needed to understand how different life histories of rockfish might interact with kelp farms. While kelp farms could provide habitat connectivity along salmon migration routes or nursery habitat for rockfish, the timing of kelp growth and harvest may limit these opportunities.

Forage fish, such as Pacific herring (*Clupea pallasii*), are also key Salish Sea species and food sources for larger fish and wildlife, contributing to the functioning of Washington's marine food web (Penttila 2007). Pacific herring lay their eggs on vegetation in the nearshore, which could include kelp aquaculture sites (Penttila 2007). As such, fish eggs could be laid on farmed seaweed, which could be considered a habitat benefit or an impact, depending on whether

the eggs are disturbed during farm maintenance and/or harvest. Current guidance is that kelp farms should be sited away from known herring spawning sites; however, these sites may shift and change over time (Hay et al. 2009). If herring eggs are observed on a farm, farmers must consult with the Washington State Department of Fish and Wildlife (WDFW) and DNR. DNR Stewardship Measures provide actions for observed herring spawn on aquatic land leases and require harvest and in-water activities to cease until eggs are absent upon follow-up surveys (DNR, pers. comm., 2025).

In Alaska, herring reproductive cycles often overlap with kelp aquaculture harvest times. If herring spawn on cultivated kelp, permits prevent farmers from harvesting the product (Hollarsmith et al. 2025). To prevent product loss and potential impacts on herring roe survival, researchers have tested strategies to deter herring spawning on kelp farms. The method showing the most promise was the creation of a bubble curtain around the farm, which mimics the bubble-netting behavior of humpback whales (*Megaptera novaeangliae*), which is a whale foraging strategy used to catch herring.

Siting guidelines encourage farmers to site farms outside of known herring spawning areas. Conversely, the potential exists for farmed kelp to provide reproduction habitats for forage fish, so long as the farm location is advantageous to roe survival, the eggs are not disturbed or harvested, and the eggs are allowed to hatch. This potential ecosystem service is not widely studied and could be an area of interest, particularly in areas like Washington state, where forage fish populations are historically in decline, and population boosts would benefit other keystone species, such as salmon.

Benthic impacts

Inherent to floating aquaculture farms, including seaweed, is the potential for the farmed seaweed and infrastructure to shade the benthic environment below the farm. Due to this potential impact, siting farms away from areas commonly used by marine mammals and from sensitive benthic habitats is an important aspect of farm planning and siting. Overwater structures like longlines and underwater

impacts like moorings may negatively impact benthic habitat through seafloor shading and mechanical abrasion caused by human operations, which could impact habitats like seagrass by reducing light transmission and plant growth, contributing to plant mortality and fragmentation (Eklöf et al. 2005; Waycott et al. 2009; DNR 2015; Buckner et al. 2023).

DNR Stewardship Measures require that farm infrastructure (growlines, support lines, anchors, work barges, etc.) not to be located above existing aquatic vegetation (native eelgrass or kelp) on state-owned aquatic lands (SOAL; DNR, pers. comm., 2025). Additionally, anchors and lines should be placed and managed to prevent damage to subtidal habitats. (DNR, pers. comm., 2025). DNR created a guide, *Native Aquatic Vegetation Survey Protocol: Siting Seaweed Farms* (DNR 2024a), to clarify steps in the leasing process to ensure the footprints of the prospective seaweed farms do not shade out naturally occurring macroalgae or eelgrass beds. This survey is required as a first step in the aquatic leasing process. More information about the vegetation survey can be found in Section 4 of this document ([policy implications and partnerships](#)).

Marine mammal entanglement

There have been no reported instances of marine mammal entanglement in seaweed aquaculture infrastructure (Grebe et al. 2019). In most cases, toothed whales (suborder Odontoceti; including the Southern Resident killer whale, a species listed under the U.S. Endangered Species Act) that echolocate can avoid interactions with aquaculture gear (Wilding et al. 2021). Whales that are unable to echolocate (e.g., humpbacks and gray whales [*Eschrichtius robustus*]) are considered to be at a higher risk of accidental entanglement (Wilding et al. 2021). Siting activities should include understanding high-use areas for whales and ensuring the proposed farm location avoids migration routes and feeding and breeding grounds (Fujita et al. 2023; Kelly 2023; Buckner et al. 2023). Additionally, loose, vertical lines could be the most likely to become entangled, and keeping buoy and anchor lines taught is an important better management practice (ICES [International Council for the Exploration of the Sea] 2023).

DNR Stewardship Measures require all lines to be taught and may require seasonal removal of gear after harvest to reduce or avoid interactions with marine mammals (DNR, pers. comm., 2025).

While the current risk of marine mammal entanglement is low, such a situation could have an incredibly high impact; research into this issue should continue for both nearshore and offshore waters (Cottier-Cook et al. 2016; Grebe et al. 2019; Considine et al. 2023). Efforts are underway to further reduce any potential interactions between seaweed aquaculture and whales, including the development of composite lines or lines that break under tension, such as tension from a whale interaction (Kross et al. 2021). The Composite Recycling Technology Center is currently testing the use of these composite lines for aquaculture in Washington using recycled carbon fiber cables. Another potential innovation employs the use of a marine mammal alert system to reduce aquaculture interactions. For example, the World Wildlife Fund is working with the University of New Hampshire to engineer a sensor that would detect and then alert farmers to an entanglement (World Wildlife Fund n.d.).

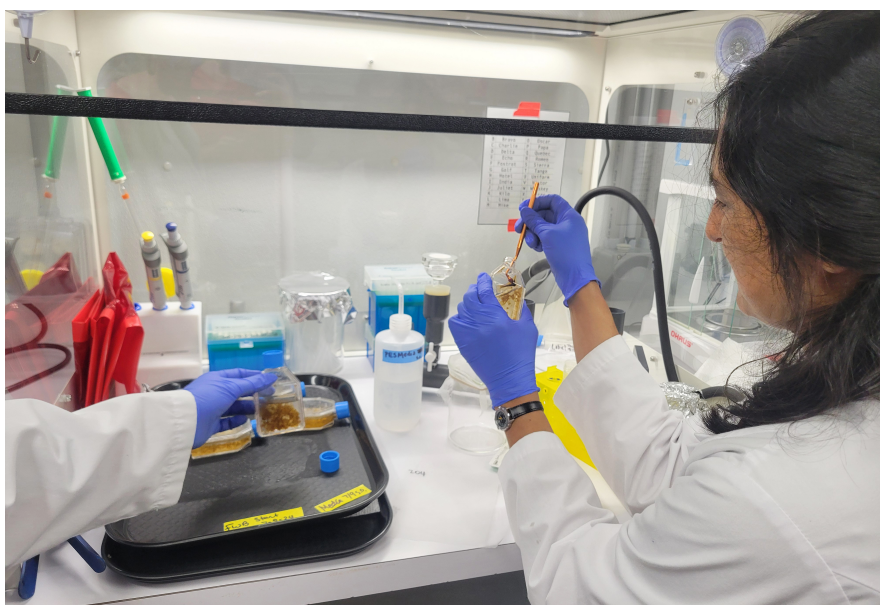
Kelp genetics

Kelp aquaculture contribution to kelp restoration

Open-water kelp aquaculture has the potential to benefit wild kelp beds by providing increased seedstock via spore dispersal, if proper genetic considerations are taken into account (O'Shea et al. 2019; Theuerkauf et al. 2022). Kelp farms that have habitat and hydrodynamic connectivity with wild beds or suitable habitat could theoretically improve local spore supply and contribute to native kelp bed restoration (Burnett et al. 2024). However, this potential benefit would depend on local kelp genetics research, farmer interest, and state agency

support to leave kelp in the water long enough to allow reproductive material to develop, which can sometimes conflict with state guidance or farm harvest timelines (Eger et al. 2020; Gierke et al. 2023).

Efforts are underway to understand kelp genetic diversity and implications for restoration and aquaculture purposes across the country (Purcell et al. 2025) and in the Pacific Northwest (Gierke et al. 2023; Bemmels et al. 2025). For example, a recent study showed distinct genetic differentiation between bull kelp along Washington's Pacific coast and Strait of Juan de Fuca versus the inner Salish Sea (Gierke et al. 2023). The seascape genetics approach indicated a reduction in bull kelp diversity moving from the Pacific coast of Washington into the inner Salish Sea (South Puget Sound; Gierke et al. 2023). Further, Bemmels et al. (2025) showed that in British Columbia and Washington, bull kelp and giant kelp populations have a strong genetic structure, with clusters that could be used for aquaculture management and restoration to guide the collection of *sori* (kelp reproductive tissue). Locally, DNR, PSRF, and the University of Washington are working together to investigate the population genetics structure of wild sugar kelp in Washington, which will help inform future restoration techniques and aquaculture policy (A Stote, pers. comm., 2025).



Kelp gametophytes in hatchery experiments (© PSRF)

Potential of overharvesting native kelp species

In the U.S., sori are often harvested from wild kelp populations that are then grown in a hatchery setting, raising concerns about the well-being of wild populations, including overharvesting, impacts on genetic diversity, and the risks of spreading disease, parasites, or nonnative species (Cottier-Cook et al. 2016; Grebe et al. 2019; Considine et al. 2023).

If sorus tissue is overharvested from wild kelp beds, the replenishment and recruitment of natural populations could be impacted, in turn negatively affecting the biodiversity and productivity of wild kelp (Grebe 2021). While the seaweed aquaculture industry in Washington is not currently large enough to greatly impact the life cycle of kelp communities due to wild sorus harvest alone, the state's stakeholders should carefully consider and build off of the best available science to maintain updated sori collection protocols.

Kelp genetic diversity

Genetic diversity concerns arise when sori from one geographic region are harvested for farming in a different geographic region, when selective breeding is used, or when limited genetic stock or parental blades are used. Farmed kelp with a different genetic composition from that of wild populations could cause genetic erosion of local kelp populations over time, trending toward a genetic makeup similar to that of the farmed species (Grebe et al. 2019).

Smaller populations of kelp are at risk for inbreeding, demographic stochasticity, and genetic drift. Also, populations with lower genetic diversity may be associated with decreased resilience to stressors and a reduced ability to adapt (Gierke et al. 2023; Bemmels et al. 2025).

Several practices can help reduce genetic impacts on wild populations. First, seedstock guidelines may include using genetic strains and reproductive materials from the same bioregion as growout sites (Yarish et al. 2017; Grebe et al. 2019; Considine et al. 2023). For example, in Alaska, farmers gather spores annually from at least 50 wild kelp plants within 50 km of the kelp farm to ensure both the

farm and any spores it releases have a diverse genetic makeup similar to the wild populations (Stopha 2020). In Washington, DNR currently requires "sori to be collected from wild populations as close to the farm site as possible or within the same oceanographic sub-basin as the farm" (DNR 2024b). Second, before the maturation and release of sori, seaweed crops should be harvested to prevent interaction with wild populations (currently required by DNR leases). Third, sterile strains of kelp can be created that cannot reproduce at all (Loureiro et al. 2015). As climate change and other stressors impact native kelp beds, finding ways that kelp aquaculture can support natural populations could become increasingly important.

Fundamental research is needed to assess genetic resources and develop adequate genetic conservation policies (Loureiro et al. 2015), particularly in Washington state. This effort would include mapping the genetic and phenotypic structures of wild seaweed populations to better understand the risks of gene flow and prevent genetic contamination from monocultures (Mao et al. 2020; Coleman et al. 2022; Considine et al. 2023). Applicable biosecurity and genetic diversity regulations and examples from other states, such as Alaska, are discussed further in this report's ["policy and regulatory considerations"](#) section.

Biosecurity and invasive species

Kelp diseases

Seaweeds can be affected by infectious and noninfectious diseases. *Infectious diseases* can be transferred by agents such as bacteria, fungi, and viruses, and *noninfectious diseases* may present when seaweed is under physiological stress (Spagnuolo and Genovese 2024).

A kelp population's disease resistance is directly linked to its genetic diversity (Gjedrem and Andersen 2005; Grebe et al. 2019). Consequently, seed production methods that create low genetic variation may leave kelp more susceptible to disease, which has occurred in Asia and Africa (Halling et al. 2013; Hafting et al. 2015; Grebe et al. 2019). Additionally, as ocean temperatures rise due to climate

change, kelp's chemical defenses are negatively affected, potentially increasing disease risk (Harder et al. 2012; Buschmann et al. 2014). As the scale of commercial cultivation increases on the U.S. West Coast, disease risks will become more relevant, and a kelp-disease outbreak could greatly impact the industry, associated human communities, and wild kelp populations (Buschmann et al. 2014; Grebe et al. 2019).

Because of seaweed aquaculture's early stages in Washington, research is needed on pathogens and diseases. Vigilance is vital to detect symptoms, such as deformed or destroyed tissues, as well as incipient outbreaks. This vigilance can help avoid major outbreaks and ultimately result in greater biosecurity of wild kelp populations (Buschmann et al. 2014).

Introduction of invasive kelp species

Cultivating nonnative kelp species could lead to the establishment of invasive species that compete with native species for space, light, and nutrients. Given the genetic distinctiveness of kelp populations in Washington waters, the release of farmed nonnative reproductive seaweed into the natural environment could pose a high risk of environmental damage (Campbell et al. 2019; Gierke 2019; Buckner et al. 2023).

Washington State requires permits to import seaweeds and may limit imports if potential risks to native species exist (WAC 220-370-220; Marine Plant Aquaculture Disease Control 2025). To reduce the introduction of invasive "hitchhiker" species within the state, WDFW also restricts the transfer of seaweeds between some water bodies. WDFW prohibits the import of seaweed from outside Washington for aquaculture. Because a large number of native Washington seaweed species can be farmed and significant potential drawbacks come with farming nonnative species, there is a strong argument for only farming native species in Washington state.

See the ["policy implications and partnerships"](#) section for more information about transport regulations.

Farm planning and site selection for in-water kelp farms

The site selection process for any aquaculture activity should include an assessment of local political, regulatory, social, environmental, operational, logistical, and economic factors. Siting criteria are dependent on the environmental needs of the target species; federal, state, Tribal, and county-level policies and regulations; and the interests of local communities and stakeholders (Buck and Langan 2017; Lester et al. 2022; Considine et al. 2023)

A key principle for implementing restorative aquaculture is strategically placing farms to optimize environmental benefits, such as improved water quality and habitat provisioning (TNC 2021; Theuerkauf et al. 2022). Important considerations for planning the development of farms with restorative practices include the following (TNC 2021):

- Siting and local environmental conditions must be considered so that sensitive habitat is not impacted and ecosystem services can be provided.
- The species cultivated are a significant driver of the benefits that can be provided (e.g., cultivating native seaweed).
- Appropriate farming gear that enhances habitat and does not endanger marine mammals or ecosystems should be used.
- Farm management practices should not degrade water quality or habitat and should be mindful of key habitat cycles (e.g., not harvesting seaweed during forage fish spawning).
- The intensity and scale of culture should take into account the needs of the water body and avoid seasonal or cumulative negative effects.

A collective understanding of appropriate site selection criteria will assist aquaculture industry practitioners, government officials, and the public, and will ensure parameters are created around expectations while benchmarking progress as the seaweed aquaculture industry grows (TNC 2021).

Siting considerations for kelp farms in Washington waters

Environmental parameters

The main seaweed species currently considered for commercial cultivation in Washington are sugar kelp and bull kelp. Winged kelp is another kelp species of interest, but it is not currently grown commercially in Washington. As described in the previous sections, to thrive, these kelp species require cold, nutrient-rich water; sufficient light, water flow, and salinities; and a healthy ecosystem. Using spatial modeling tools or monitoring environmental conditions at potential sites can increase farm success.

Figure 3 shows environmental parameters to measure or consider in siting exercises. Also, Table 1 provides references to the current understanding of environmental thresholds for sugar and bull kelp.

In addition to considering environmental variables required for kelp growth and productivity, farms should be sited for accessibility and reduced conflict with the natural ecosystem and existing marine uses.

Accessibility

Water access points, such as docks or boat ramps, are important to consider when selecting a site. The further away a seaweed farm is from these points and/or production facilities, the greater the cost of business (due to fuel use and boat wear) and carbon emissions (Flavin et al. 2013). Additionally, the kelp growing season (approximately November to May) co-occurs with the stormy season that can produce high winds and waves, potentially increasing the danger of accessing the site by boat if located far away from a port (GreenWave Hub n.d.-b).

Siting away from critical habitat and important species

Negative interactions with critical habitat, as well as endangered and threatened species, should be avoided when siting a farm. For example, submerged aquatic vegetation (e.g., eelgrass) provides important and diverse microhabitats for species such as herring, larval and adult crabs, juvenile salmon, and clams. Overwater structure can negatively affect seagrasses due to shading, which impacts seagrass biomass and growth (Moreno et al. 2021).

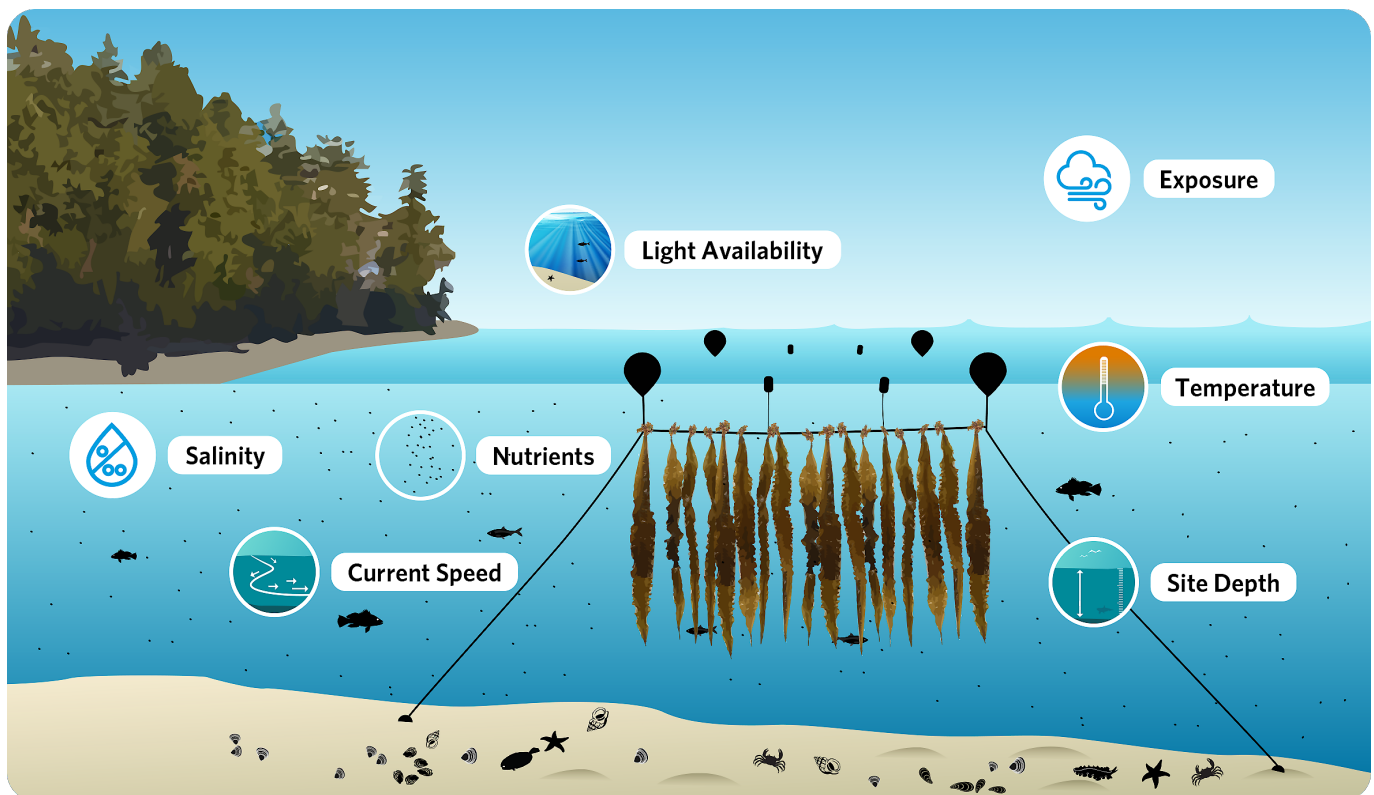


Figure 3. Environmental parameters for siting kelp farms.

Table 1. Summary of environmental parameters and thresholds for sugar and bull kelp, adapted from Buckner et al. (2023).

Siting factor	Description	Threshold
Current speed	Adequate water flow is necessary for delivering nutrients and flushing out detritus (Freitag 2017). Too high a water velocity, however, can result in crop, rope, or mooring damage (Buckner et al. 2023).	1 m/s at peak ebb/flood (Buckner et al. 2023)
Site depth	Farming kelp in nearshore waters should have a site depth (at mean low water [MLW]) deep enough to ensure the crop remains suspended throughout a tidal cycle.	≥ 3 m (bull kelp) or ≥ 5 m (sugar kelp) deep (Mumford 2007; Blasco 2012)
Nutrients	Nutrient levels fluctuate depending on the time of year. For example, nitrate levels rise in the winter months and decline in the summer months, which can affect the quality of farmed kelp (Stephens et al. 2023).	Nitrate: 1–10 $\mu\text{mol/L}$ (bull kelp); 10–20 $\mu\text{mol/L}$ (sugar kelp) Phosphate: $> 0.3 \mu\text{mol/L}$ (bull and sugar kelp) (Simonson et al. 2015; Muth et al. 2019; Buckner et al. 2023)
Temperature	Kelps local to Washington grow in water temperatures between 41 and 59 °F (5 and 15 °C; Flavin et al. 2013) and may be threatened by periods of extreme heat (Weigel et al. 2023). Water temperatures above 18–19 °C may cause stress or mortality (Maxell and Miller 1996; Simonson et al. 2015).	≤ 18 °C (bull kelp; Muth et al. 2019) ≤ 19 °C (sugar kelp; Simonson et al. 2015)
Light availability	The depth at which growlines are placed should be based on the light available at the site (Stephens et al. 2023). Depth may be impacted by water clarity and/or sun exposure (GreenWave Hub n.d.-c).	20–40 $\mu\text{E m}^{-2} \text{s}^{-1}$ (bull and sugar kelp; Buckner et al. 2023)
Salinity	Avoid areas that have steady freshwater input, such as the mouth of a stream or river, as the fresh water could negatively affect bull kelp growth (Stephens et al. 2023).	26–31 PSU (bull and sugar kelp; Mumford 2007)
Exposure	Sites that are exposed to wind and waves may be more vulnerable to gear failure and crop loss. Considering the site’s exposure is important for avoiding environmental and financial risk.	Is the site sheltered or exposed?

Additional studies are needed on the degree to which temperate kelp farms reduce light availability for benthic communities. At this time, DNR requires kelp farms to provide a 25-ft buffer from eelgrass beds to reduce the potential impacts of shading from mature kelp canopies (DNR 2024a).

As mentioned in the “[environmental benefits and impacts](#)” section, the floating structures and food availability provided by natural kelp beds serve as important habitats for fish (e.g., rockfish and salmon) and other marine species (Calloway 2020;

Shaffer et al. 2020). Understanding ecosystem interactions and the timing of harvest are important considerations in farm planning.

Additionally, researching and avoiding marine mammal feeding areas and migration corridors are important for reducing the likelihood of gear interaction, entanglement, and behavioral disruption (Miller 2020).

Consideration of other ocean users

Marine waters are busy spaces, with many users and uses. When siting a kelp farm, it is important to research mandated setbacks, understand community interests and concerns, conduct outreach with nearby Tribal Nations, and abide by Tribal U&As. Restricted areas that require a setback include shipping lanes, maintained channels, navigation aids, environmental sensor buoys, submarine cable areas, active ocean disposal sites, munitions and explosives of concern, wrecks and obstructions, ferry routes, salmon river inlets, and bridges.

Coordinating with Tribes is imperative for siting, permitting, and operating a seaweed farm. Seaweed farm infrastructure could interfere with beach-seine and drift-net fisheries that target salmon, Dungeness crab (*Metacarcinus magister*), shrimp, and geoduck fisheries, among other treaty fisheries that Tribes operate. It is recommended that sites be located in areas that avoid or minimize conflicts with Tribal fisheries (Buckner et al. 2023). Early coordination with Tribes will help identify potential conflicts and foster collaborative approaches to the seaweed farm's site selection and operation.

The consideration of pre-existing water and land uses adjacent to a potential farm site is important and could increase the level of social acceptance if thoughtfully factored into siting decisions (Buckner et al. 2023). In Maine, new and expanding seaweed farms have faced some social resistance due to the lack of social license. A study by Whitmore et al. (2025) found it essential to build community relationships before applying for permits and, to a



Crab and kelp at Jefferson Head, Puget Sound, WA (© PSRF)

greater extent, before finalizing lease applications. The authors described understanding the host community's social fabric and culture as a necessary part of site selection and recommended connecting with community members and industry stakeholders outside of what is required during the permitting process (Whitmore et al. 2025). For more information, see the "[public perception and social license](#)" section found later in this situation analysis.

During site selection, it is suggested that farmers focus on areas already built out, such as docks and piers, areas with existing fisheries access, and existing shellfish aquaculture sites (Buckner et al. 2023). Furthermore, farmers should consider the seasonal ramifications that affect potential sites (Hobday et al. 2016), such as the conflicts between late fall salmon fisheries and winter crab fisheries.

Site selection tools

Various organizations have developed tools that may assist with site selection in Washington (summarized in Table 2 and detailed in subsequent subsections). As more potential farmers seek permits, pathways are being forged for what seaweed farming will look like in the state. These tools can contribute to data-driven, informed decision-making.

The following paragraphs provide further detail about the tools listed in Table 2, where links to the tools are provided.

The NWIFC releases a report every four years that includes an analysis of Washington's watersheds to gauge progress toward salmon recovery. As various marine factors are monitored in the NWIFC *State of Our Watersheds* report, this resource could be useful in siting seaweed aquaculture, particularly as potential farmers should always take into account Tribal areas, interests, and concerns. The report, written by the 20 treaty Tribes in Western Washington, includes information broken down by regions and areas of Tribal interest, with different indicators and special topics identified by each Tribe to highlight priorities for their region's environmental health. It also includes information about the Puget Sound and Pacific coast regions more generally.

Communicating with area Tribe(s) before siting a farm is of the utmost importance.

DNR's Puget Sound Eelgrass Monitoring Data Viewer provides monitoring data at select sites in Puget Sound. It could help prospective farmers make decisions about site selection to avoid eelgrass areas.

The Washington State Department of Health (DOH) interactive Commercial Shellfish Map Viewer identifies commercial shellfish growing areas and includes information on water quality and commercial harvest site locations, among other data.

The Washington State Department of Ecology (ECY) maintains the Washington State Coastal Atlas, providing information on public beaches, shoreline properties, biology, and slope stability.

The NWSC's web-based application, SoundIQ, shares data collected in collaboration with Marine Resource Committees. The app features information on the Puget Sound area regarding marine plant and animal species, shoreline restoration, kayak-based bull kelp monitoring, and more. Also, users can create custom maps.

PNNL's Salish Sea Model can simulate hydrodynamic and water quality processes in the Salish Sea, including circulation, currents, water temperature, salinity, sediment diagenesis, acidification, and water quality variables (ECY n.d.-a). These characteristics are important for prospective seaweed farmers to consider and could make or break their ultimate site selection.

Finally, the federal government has developed spatial tools that provide human-use and natural-resource information relevant to local, state, and federal aquaculture permitting. The NOAA National Centers for Coastal Ocean Science maintains the CASS tool kit that provides science, guidance, and technical support to coastal managers to sustainably grow aquaculture while maintaining and improving ecosystem health. Additionally, the NOAA National Ocean Service's Coastal Decision-Making Tools can be used to explore information and the implications of different impacts, such as sea level rise.

Table 2. Tools that can support seaweed aquaculture site selection.

Organization	Tool	Usefulness for site selection
NWIFC	State of Our Watersheds Report	Use the report’s marine factors to site a farm. Gain a better understanding of Tribal interests using Tribe-specific indicators and special topics highlighting priorities for their region’s environmental health.
DNR	Puget Sound Eelgrass Monitoring Data Viewer	Avoid eelgrass areas with monitoring data at select sites in Puget Sound.
DOH	Commercial Shellfish Map Viewer	See the classifications for commercial shellfish growing areas. Get information on water quality, locations for commercial shellfish harvests, polluted waters, etc.
ECY	Washington State Coastal Atlas	Assess data on public beaches, shoreline properties, biology, and slope stability. The Marine Spatial Mapping Portal that was used to create the state’s marine spatial plan is now housed by the Coastal Atlas.
NWSC	SoundIQ	Get information on marine plant and animal species, shoreline restoration, kayak-based bull kelp monitoring, and more. Create custom maps.
PNNL	Salish Sea Model	Simulate hydrodynamic and water quality processes in the Salish Sea (e.g., circulation, currents, water temperature, salinity, water quality variables).
National Centers for Coastal Ocean Science	Coastal Aquaculture Siting and Sustainability (CASS)	Aimed at coastal managers. Get support to sustainably grow aquaculture while maintaining and improving ecosystem health.
National Ocean Service	Coastal Decision-Making Tools	Explore related information and the implications of different impacts, such as sea level rise.

Farm design for commercial applications

Both farm siting and farm design influence the environmental benefits, economics, and social outcomes of an aquaculture business. Thus, farmers must consider what design is best suited for a given site. Equipment used for commercial seaweed farming typically includes an array of floating growlines suspended horizontally below the surface and attached to mooring lines, anchors, and buoys (GreenWave n.d.-a). The spacing of lines influences crop productivity through competition for light and nutrients (Stekoll et al. 2024). Selective breeding of

kelp species that withstand denser growing conditions could increase yield; however, current genetic restrictions would prevent this practice in the Pacific Northwest (Stekoll et al. 2024).

In a study conducted by Whitmore et al. (2025), Maine shellfish and seaweed farmers shared ways they were working to build social license. Operational practices like “keeping a tidy farm” and “reducing impacts” (e.g., reducing lost gear) helped build trust with the local community (Whitmore et al. 2025). Investment in winter-storm-ready infrastructure is critical as the peak cultivation period and strongest storms occur during the winter months in



Cascadia Seaweed Farm (© Jenn Burt, Nature United)

Washington (Buckner et al. 2023). Farmers must consider the farm's mooring tensions at different kelp biomass levels and varying current velocities and wave frequencies to optimize farm designs and safety during storm events (Fredriksson et al. 2023).

Potential seaweed farmers can access a growing number of resources online. GreenWave's Ocean Farming Hub (www.greenwave.org/hub) provides training courses and how-to videos; interactive tools for designing a farm, creating farm gear and equipment lists, and getting information on permitting; and a dedicated farming community. The National Sea Grant Seaweed Hub (seaweedhub.extension.uconn.edu) contains additional resources, including manuals, state-specific resources, information on work groups and webinars, and Sea Grant publications.

Offshore siting

The scale of a seaweed farm can depend on its location. Offshore, open-ocean seaweed farms operate similarly to coastal production by using submerged growlines but often at a larger scale. Mechanization is required for offshore farms by adapting practices and equipment from nearshore farming to efficiently tend, handle, harvest, and transport seaweed. The world's first mechanical harvest occurred in August 2022 at an offshore seaweed farm in Europe by Netherlands-based North Sea Farmers. The harvest used a fishing boat outfitted with an electric-powered harvester as well as an automatic bagger (The Fish Site 2022). While more expensive and carrying more complexity and risk, mechanical harvesting could allow for industrial-scale production

in deeper, more exposed waters (Business Norway 2024).

The U.S. Department of Energy (DOE) Macroalgae Research Inspiring Novel Energy Resources (MARINER) Program developed funding opportunities for research and seed pilot projects for large-scale, off-shore seaweed aquaculture in the U.S. (O'Shea et al. 2019). The project focuses on investigating technologies to develop high quantities of biomass for bio-fuel to meet U.S. energy demands, as well as other potential markets. MARINER funded a life-cycle analysis for offshore macroalgae production (from nursery to cultivation and harvest) to understand offshore seaweed production potential, greenhouse gas emissions from production, and potential return on investment (Kwon et al. 2024). The life-cycle analysis revealed that the greenhouse gas emissions to produce each dry metric ton of seaweed harvested varied greatly between pilot projects, but combustion emissions from diesel fuel were the greatest contributor to production emissions (Kwon et al. 2024).

Despite the potential (as investigated by DOE's MARINER program), such projects have not been executed in North America due to federal permitting challenges, the lack of precedent, and the need for offshore operations to achieve massive scale to achieve stable profits. Locally, offshore farms in Washington state may run the risk of marine space-use issues, less shoreline protection, and higher costs (Buckner et al. 2023).

Storm preparedness

In Washington, the peak cultivation period and strongest storms coincide during the winter months (Buckner et al. 2023). Farmers should site farms with storm events in mind and should develop a written plan that details the steps to take depending on the forecasted intensity of the storm so that all team members are aware of the chain of action. Regular inspections to evaluate lines, anchors, and other gear are essential and can also reduce the likelihood of gear failure during a storm event.

Co-location with existing infrastructure

Using existing facilities, equipment, and other resources could alleviate start-up costs for farmers (Considine et al. 2023). Co-locating may also create easier entry into seaweed cultivation through the use of existing leases (Engle et al. 2018; Langton et al. 2019; Ehrhart and Doerr 2022). In the nearshore, there could be opportunities to site aquaculture within existing port infrastructure (e.g., Sunken Seaweed's work with the Port of San Diego), alongside shellfish aquaculture (e.g., Blue Dot Sea Farms' co-culture of Pacific oysters and sugar kelp), or as a co-location operation (e.g., Lummi Island SeaGreens' co-location with reef net structures).

In the offshore environment, the DOE's ARPA-E offshore wind energy technology project is well underway on the U.S. East Coast, in the Gulf of Mexico, and in California. (ARPA-E stands for Advanced Research Projects Agency-Energy.) These endeavors indicate that offshore aquaculture and ocean-based renewable energy are two new industries of interest for research and development. While this focus has not materialized in Washington state, Trident Winds sent an unsolicited lease request to the U.S. Bureau of Ocean Energy Management in 2022 to construct a floating offshore wind farm that would be located 43 mi off the Olympic Peninsula Coast (Turner 2022). If offshore wind farms like this proceed, they may provide opportunities for seaweed aquaculture demonstration farms.

However, co-locating these two industries could ensnare them in complex regulatory processes, cause unforeseen negative interactions between the energy devices and aquaculture activities, and raise stakeholder concerns about community and environmental impacts (Freeman et al. 2022). Furthermore, structures must withstand Washington's high wave energy, and farm designs may need to be adapted (Buck and Langan 2017; Goseberg et al. 2017).



Section 3:

Investigating economic viability

Key takeaways

- The U.S. primarily grows seaweed for human consumption and cosmetics, but the market is beginning to expand as more seaweed products become available for U.S. consumers.
- Seaweed aquaculture is a nascent industry in Washington and North America, and it will need to innovate and expand, with an emphasis on novel and niche markets, to compete with the larger, global market.
- Washington lacks well-established market streams for seaweed due to the industry's nascence and a lack of processing facilities.
- There are near-term economic opportunities for farmed Washington seaweed to be processed and find markets in food products, fertilizers, animal feed, biostimulants, cosmetics, and bioplastics.
- A limiting factor in the seaweed market in Washington is the lack of harvesting, processing, and distribution infrastructure.
- Collaborative organizations, co-op models, and/or biorefinery approaches could hold great value for farmers in Washington as the industry grows and they look to develop processing infrastructure to accelerate market opportunities for seaweed.
- Many Tribes have used native seaweed as a traditional food source since time immemorial, have a vested interest in seaweed cultivation and harvest, and could benefit from additional farmed seaweed for food and products.

Market opportunities

The U.S. has a shorter, less expansive history of seaweed cultivation compared to many Asian countries, where seaweed is consumed and used as a commodity (Kotowicz et al. 2024). Asian seaweed markets have deeper experience and lower costs due to the high demand for seaweed products, and the North American industry may experience barriers to entry due to the region's higher cost of growing seaweed, lack of infrastructure and processing facilities, and fewer market channels to support and sustain current farmers and new entrants. Below, we discuss existing and future market opportunities for Washington producers.

Blue Dot's Seacharrones

Sugar kelp (*Saccharina latissima*) grown at Blue Dot Sea Farms is processed into value-added kelp food products called Seacharrones and sold under the brand name Blue Dot Kitchen (bluedotkitchen.com).

Existing markets

At this time, seaweed produced in Washington is predominantly sold for human consumption and cosmetics. Sugar kelp is used for value-added kelp snacks, seaweed salts, and restaurant dishes. Seacharrones, a kelp snack produced by Blue Dot Sea Farms, uses kelp grown by independent U.S. farmers and could become a market stream for new growers in Washington if local processing infrastructure develops. To address this need, existing and prospective farmers are interested in exploring processing capacity for kelp grown in Washington waters and beyond (J Kroman, Blue Dot Sea Farms, pers. comm., 2025).

Sol Sea Cosmetics, a tank-based seaweed aquaculture farm, was once located at the NOAA Manchester Research Station. It produced seaweed species

for high-end skincare products that integrated vitamins, lipids, minerals, and proteins from the seaweed. Additionally, the company was involved in research to inform aquaculture technology and explore other potential products, including food, fertilizers, and animal feeds (Banse 2022). The company is no longer in operation.

Near-term market opportunities

Seaweed farming in North America has only reached a modest scale in recent years, and most of the seaweed farmed in the U.S. is currently used in food products (McKinley Research Group 2021). Food products include value-added seaweed snacks and salads, frozen kelp puree cubes, soup mixes, jerkies, chips, popcorn, kelp burgers, salsas, and sauces.

A lack of growth in the current U.S. seaweed market may be attributed to a lack of consumer understanding of and familiarity with seaweed and kelp products (Bolduc et al. 2023); seaweed product studies have identified familiarity as a significant indicator of consumer acceptance and preference (Anusha Siddiqui et al. 2022; Embling et al. 2022; Bolduc et al. 2023). Consumer education on seaweed products may help bridge the gap between consumer familiarity with the products and their willingness to try them.

Food-based seaweed operations could use several marketing strategies to gain market share by using market verification and eco-branding (e.g., organic certification), promoting a product's nutritional value and health benefits, and making comparisons with land-based agriculture (Waters et al. 2019). Many seaweeds have high nutritional values because they are sources of high dietary fiber, essential nutrients—such as omega-3 and omega-6 polyunsaturated fatty acids, vitamins, and iodine—and in some species, antioxidants. Select species, like sugar kelp, also contain high protein and low fat levels (Kotowicz et al. 2024). With demand for locally grown food rising (Donahue et al. 2014), opportunities for locally produced seaweed in Washington could grow over time.

Bolduc et al. (2023) conducted a study that found a significant increase in the consumer willingness to pay (i.e., the maximum amount a consumer is willing to pay for a product) for kelp products after education on ecosystem services. In this study, consumers ranked supporting services as the most important, followed by regulating services, culture services, and provisioning services. The study concluded that education on ecosystem services could be used as a valuable marketing tool by public and private entities alike.

Fertilizers and animal feeds have also been highlighted as potential near-term growth markets for the North American seaweed industry, given their established supply chains (Piconi et al. 2020; McKinley Research 2021). These two market streams have minimal processing requirements and have generally relied on wild-harvested seaweeds available at low costs. Products include soil amendments as well as crystallized powders and liquid fertilizers for both commercial agriculture and home applications; they have proven to be better for soil microorganisms and can be used on organic farms (McKinley Research Group 2021). Additionally, seaweed can be used as a supplement for cattle feed in the form of seaweed meal, providing nutrients, minerals, and metabolites (Morais et al. 2020). Canadian-based seaweed farming company Cascadia Seaweed is currently in the research and development phase on two cattle feed supplements that could provide the co-benefits of nutrition and methane emission reductions for cattle (Cascadia Seaweed n.d.).

In addition to these markets, TNC and Bain and Company (2023) conducted an analysis of novel markets to determine the most likely markets to support geographies like North America in the near term to significantly grow the industry over the next five to 10 years. While multiple potential and current markets were analyzed—including cattle and sheep feed, human food, fossil fuels, biochar, aquaculture feed, poultry feed, and pig feed—the top two markets determined to have the greatest potential were agricultural products (specifically biostimulants) and bioplastics (Table 3). For both of these markets, there were feasibility and proven use cases using

wild seaweeds, and the markets could be meaningful given their size and growth trajectories.

Compared to other U.S. states such as Maine, Washington has fewer farms and arguably more state-level permitting challenges (Kotowicz et al. 2024); these factors may serve as barriers to gaining an early foothold in national seaweed markets. Ultimately, though, for all states, a common issue among the nonfood near-term markets is that many of them currently rely on wild seaweed, which has been and most likely will continue to be cheaper than farmed seaweed. Growth within these markets should be paired with protections for wild seaweeds to avoid negative externalities from encouraging the growth of a farmed seaweed market.

Tribal Nations

Many Western Washington Tribes have seaweed-related programs in which they tend, gather, grow, harvest, preserve, and prepare traditional foods; foster cultural activities; provide social connectivity; and promote health and well-being among their Tribe. Food sovereignty and connection with traditional foods are foundational aspects of the Coast Salish Tribes' way of life. Each Tribe or band practices different subsistence practices. Collaboratives like the Indigenous Aquaculture Network (indigenouaquaculture.org) bring together Pacific Northwest Tribes and First Nations, along with Native Hawaiian and Indigenous communities, to advance Indigenous aquaculture. By sharing unique living traditions, the network develops strong cross-cultural learning and supports collective efforts in aquaculture. Distributing kelp through Tribes to their members and/or incorporating seaweed into existing Tribal food programs could be important uses of seaweed cultivated in Washington.

Table 3. Expected outlook across seaweed end markets without intervention to stimulate demand in specific end markets, reproduced from unpublished results from the TNC and Bain and Company 2023 analysis.

End use	Share of market	Primary examples	Relevant seaweed types	Future growth	Growth outlook
Human consumption (Food)	~ 40%	- Meat and fish dish ingredient (sushi, noodles, salads) - Agar as plant-based gelatin - Food seasoning	All	~1-3%	→
Human consumption (Additives)	~ 40%	- Carrageenan as a thickening agent - Agar as a thickening / stabilizing agent	- Red - Brown	~1-3%	→
Animal consumption (Food)	~ 5%	- Abalone (mollusk) feed - Cow feed (nascent)	- Red - Brown	~3-5%	↗
Cosmetics (Additive)	~ 5%	- Thickening agent - Preservative agent - Active ingredient	- Red - Brown	~1-2%	→
Pharmaceuticals	< 5%	- Binding agents - Carrier material for tablets - Direct treatment (antibacterial, etc.)	All	~1-4%	→
Biofuels / biostimulants	< 5%	Biogas / biomethane / biochars	All	~1-7%	↗
Biopackaging	< 5%	Replacement for select single-use plastics (e.g., straws, cups, lids)	- Red - Brown	~15-25%	↗

Both national and Washington farmed seaweed products need to find stable markets to be economically profitable. Potential opportunities in the market spaces include but are not limited to farmers differentiating their agricultural or biomaterials products as premium options and thus worthy of a higher price, working on industry and processing efficiencies to lower the cost of seaweed products, and/or partnering with conservationists or governments to seek out ecosystem service payments or incentives to supplement existing seaweed markets.

Supply chain considerations

One of the main barriers to increased seaweed production in the U.S. is a lack of processing and distribution infrastructure. In concert with developing

solid markets, upstream and downstream supporting infrastructure needs to be expanded, including hatcheries, processing and drying facilities, cold and dry storage space, and transportation centers.

In Washington, PSRF has developed a hatchery and seed bank to provide farmers with genetically appropriate seedstock and facilitate active kelp restoration (PSRF n.d.). Currently, PSRF, Blue Dot Sea Farms, and Pacific Sea Farms are the only producers of kelp seed in Washington. However, there are efforts to increase hatchery production by Island Mariculture (Legoe Bay Shellfish) and through workforce development skills courses (e.g., seaweed culturing) at Bellingham Technical College.

Smaller-scale businesses may benefit from community storage and processing space, as well as collective distribution centers for local businesses. An approach that also includes spatial zoning policies could be a driver of infrastructure development, especially supply chain growth (Lester et al. 2022; Considine et al. 2023). Market demand from private companies, coupled with risk-tolerant capital investments, could be major catalysts for the industry. Examples of private donor capital investments in this sector include return-seeking arrangements, grants, equity investments, and loans (Considine et al. 2023). Future investments in processing will enable the creation of marketable products, which will consequently increase consumer demand (Greene et al. 2020).

One processing activity that could be catalytic, if funded well, is establishing a seaweed biorefinery to convert seaweed biomass into multiple product streams, such as biostimulants as well as alginates, protein concentrates, and bioactive compounds that could be used to create products such as food, cosmetics, supplements, or bioplastics (McKinley Research Group 2021). Seaweed biorefineries, while not yet well established, are appealing as a concept, as they can theoretically extract multiple valuable products at one location, using as much seaweed as possible and minimizing waste. One example of an operating biorefinery is a Scottish-based group, Oceanium, which in 2023 refined 75 T of seaweed for food, health, and materials products (Oceanium 2023).

Additionally, Washington's blue economy efforts may offer opportunities for seaweed industry growth. The Washington Maritime Blue Cluster



Sporophytes seeded on twine for outplanting (© PSRF)

(maritimeblue.org) serves as a hub for collaboration between industry, the public sector, academia, training institutions, and community organizations to support innovation, collaboration, and workforce development (Washington State Department of Commerce 2020: "About Maritime Blue" section). In 2024, Maritime Blue started working with Washington kelp growers to research industry funding mechanisms, commission an economic analysis (including a look at Washington's role in the seaweed value chain), and analyze potential markets and processing needs (Maritime Blue n.d.).

In Maine, the more-established seaweed aquaculture supply chains are vertically integrated and include fresh seaweed sales at farmers markets, restaurants, and university food services; processed seaweed sales (e.g., dried or frozen); sales to wholesalers/distributors; and sales to processors (Engle et al. 2018). In vertically integrated supply chains, a single entity oversees several levels. For example, for a farm-to-table restaurant, the owner of an aquaculture operation might produce shellfish and seaweed that are then sold in dishes served at the same company's restaurant. While vertical integration allows for greater control over the product and its quality throughout the supply chain, it also requires investing in and assuming the risk associated

with the facilities needed to accomplish product integration, processing, and marketing (Engle et al. 2018).

The supply chain's makeup is important; so too is its transparency and integrity. For participants in Washington's nascent seaweed industry, consumer preferences are evolving, and the traceability, sustainability, and associated social responsibility of seafood products are becoming more important in consumption decisions (O'Shea et al. 2019). While the U.S. Food and Drug Administration (FDA) does not currently list seaweed on the Food Traceability List, it is recommended that food traceability be prioritized for seaweed products used for human consumption (Waters et al. 2019; Considine et al. 2023).



Three-ribbed kelp (NOAA, [photo](#) in the public domain)



Section 4:

Policy implications & partnerships

Key takeaways

- Opportunities for aquaculture policy improvements could enable more sustainable farms, improve permitting efficiency, and reduce barriers to entry for growers.
- Tribal review of seaweed aquaculture projects should be a first step for all farms. Support from local Tribes is highly recommended before applying for federal, state, and local permits.
- Adding seaweed-specific language to existing regulatory systems, similar to those in place for shellfish, or creating separate regulatory frameworks for seaweed would reduce confusion over permitting requirements for potential growers and provide environmental and human health safeguards.
- Adding clear policy and regulatory frameworks for seaweed aquaculture would improve transparency for the public and would support outreach and education efforts aimed at increasing social license.
- Current policies and permitting regulations for shellfish aquaculture encompass biosecurity concerns, product safety for human consumption and other uses, and genetics. In contrast, seaweed aquaculture policies and regulations lack the same level of specificity to encapsulate these core responsibilities.

Overview of the legal framework

The U.S. has developed an extensive set of laws and regulations specific to aquaculture around siting, genetics, aquatic health management, and environmental impacts (Knapp and Rubino 2016). Federal oversight, paired with additional state and local policies and regulations, creates a complicated and often uncertain permitting process (Knapp and Rubino 2016). Regulatory frameworks and standards are important for protecting the environment and farmers, encouraging investments in the country, and ensuring compliance with export and consumption standards (FAO 2013). However, they can also be cumbersome and pose challenges to sustainable growth (Engle and Stone 2013; Knapp and Rubino 2016; Lester et al. 2018, 2022). In the Pacific Northwest, regulatory complexities and permitting delays have resulted in high financial and business productivity costs for farmers (van Senten et al. 2020). Despite demand for aquaculture products, these hurdles have slowed industry growth due to fewer new entrants and the exit of existing farmers (van Senten et al. 2020).

At the state level, Lester et al. (2022) examined aquaculture policies to identify enabling legislation, regulations, and management actions to assign an enabling policy score (on a scale of 1–8) for each coastal state. In this study, Washington was given a relatively high score of 6.5 due to specific leasing regulations, supportive programs, best management practices, some multi-use spatial planning, clearly identified government contacts, state-provided regulatory guidance, state right-to-farm legislation (that includes aquaculture as a form of agriculture), some agency overlaps, and climate change policy. Washington's score, however, was impacted by non-comprehensive legislation and zoning for marine aquaculture, as well as a possible need for more agency coordination.

While shellfish aquaculture has had a longer history of regulation in Washington, interest in seaweed aquaculture is increasing. In some instances, potential farmers are unsure how to navigate the complex process of obtaining permits, and some permitting guidelines use shellfish-specific language rather



Bull kelp (© Jenn Burt, Nature United)

than seaweed-specific language. No comprehensive guide for seaweed permitting and leasing currently exists, but as the first seaweed aquaculture permits are filed, clearer permitting and leasing documents and processes may be developed based on experiences from the initial applications.

Kelp restoration permitting closely follows commercial aquaculture permitting, and the interagency Kelp Policy Advisory Group identified a need to address policy gaps on kelp recovery and restoration that may overlap with kelp aquaculture. A key recommendation of this advisory group included the creation of a document that clearly outlines different agency authorities and regulations for kelp, as no such document exists (Oster et al. 2023).

Buckner et al. (2023) noted the increase in local interest in seaweed farming despite the permitting and regulatory uncertainty. While there has been uncertainty about the exact path to permitting for parties interested in seaweed farming, several farms have already been through the current process and secured the necessary permits and leases.

Washington regulations and proprietary leases specific to seaweed aquaculture

In order to farm seaweed, prospective farmers should first work with local Tribal Nations and then obtain the necessary federal, state, and local permits. Within state waters (3 nautical miles from shore), farmers must also work with DNR, which manages and leases SOAL, to obtain a lease to farm on state-owned lands (RCW 79.105.050; Fostering Use of Aquatic Environment 2025).

Early coordination with Tribes will enable collaboration on the location and operation of aquaculture and will ensure that farm infrastructure does not interfere with territorial waters and U&As. This coordination is also imperative to obtaining permits, as many Tribes have authorities to review local, state, and federal permitting proposals by providing feedback to regulatory entities and may directly raise objections with USACE (Buckner et al. 2023). USACE

can decide not to issue a permit if it determines the proposed project would have more than a minimal impact on treaty rights (Buckner et al. 2023).

Site leasing and DNR use authorization may be obtained via the Joint Aquatic Resources Permit Application (JARPA; ORIA [Washington Governor's Office for Regulatory Innovation and Assistance] 2023). The processes require several steps involving multiple government agencies and Tribes.

An early step in the process for potential growers is contacting staff from DNR's Aquatic Resources Division to ensure the proposed land is available to lease, determine if the proposed use is appropriate, conduct a marine vegetation survey, and work with DNR to understand site-specific Stewardship Measures. DNR's Aquatic Resources Division acts as landlord on behalf of the state, managing SOAL to ensure public benefits and environmental protections while balancing commercial uses on SOAL when appropriate (DNR n.d.). If siting is on privately owned property, signed documentation from the owner is required for the various permits required to farm, and no involvement from DNR is necessary.

ORIA's Online Permitting Assistance System may help determine which local, state, and federal permits are needed for certain projects. Potential farmers should contact the local government and Washington Tribes in the area, or the NWIFC for Tribal interest determinations. When the local government reviews the materials submitted via the JARPA process, it determines if the project complies with environmental regulations, such as those set forth in the state's Shoreline Management Act of 1971 (RCW 90.58; 2025) and relevant Shoreline Master Programs (SMPs).

The SMA provides a coordinated management and protection structure for the state's shorelines and applies to all marine waters in which aquaculture occurs. Each county-level jurisdiction is required to develop an SMP that has local land-use policies and regulations to guide the use of Washington's shorelines. SMPs apply to aquaculture (ECY n.d.-c). Additionally, the potential environmental impacts of a

proposal will be assessed using a State Environmental Policy Act (SEPA) checklist (ECY n.d.-b).

The JARPA form also contains application materials for state and federal agencies, like NOAA Fisheries, the U.S. Fish and Wildlife Services (USFWS), USACE, and ECY, as well as Tribes in the state of Washington. USACE permits are necessary through section 10 of the Rivers and Harbors Appropriation Act (33 U.S.C. § 403; Obstruction of Navigable Waters Generally 2025) for the construction of any structure in or over any navigable water of the United States. During their review process, USACE will consider input from Tribal, state, and local governments; other federal agencies; interest groups and organizations; and the public.

If activities may affect an endangered species or designated critical habitat, under section 7(a)(2) of

the U.S. Endangered Species Act (16 U.S.C. § 1536; Interagency Cooperation 2025), USACE must consult with NOAA Fisheries and/or USFWS, at which time the applicant may be required to provide more information, and a biological evaluation/assessment may be required. Additionally, the Magnuson-Stevens Act (16 U.S.C. §§ 1801-1884; 2025) requires consultation with NOAA Fisheries if the action or proposed action could adversely affect Essential Fish Habitat. Before USACE issues a permit, they will consult ECY to ensure that all applicable state laws are consistent with the federal Coastal Zone Management Act (16 U.S.C. §§ 1451-1466; 2025). After going through the USACE permitting process (USACE n.d.), the JARPA will either be deemed incomplete with a request for more information or deemed satisfactory, in which case a public notice and comment period will begin.

Separate from the JARPA, state law requires an individual who commercially manages and farms cultivated aquatic products to be registered (WDFW 2023) as an aquatic farmer. If the proposed farm plans to obtain an out-of-state marine plant culture, then an import permit is required; similarly, if transferring within state waters (WAC 220-370-220; Marine Plant Aquaculture Disease Control 2025), a marine plant transfer permit (also known as a Shellfish Transfer Permit) is required. These requirements aim to reduce the risk of introducing and spreading disease agents and harmful aquatic pest organisms (WDFW n.d.). At this time, transferring marine plants from out of state is not allowed.

Obtaining leases on state-owned aquatic lands

Washington DNR requires a NAV survey. Their guide, *Native Aquatic Vegetation Survey Protocol: Siting Seaweed Farms* (2024a), highlights methods for surveying potential seaweed farm sites to establish seaweed farm leases. The purposes of the survey are to (1) ensure the footprints of prospective kelp farms do not shade out naturally occurring macroalgae or eelgrass beds and (2) help DNR make informed decisions about establishing leases. A complete JARPA must be received before a survey can



Lummi Island SeaGreens (© Riley Starks)

occur. In cases where a farm is sited in deep enough water, a NAV survey is not necessary since light penetration is not a concern.

DNR NAV surveys occur in two phases (DNR 2024a). The first phase is an optional, cursory survey that identifies areas with and without NAV in the proposed site and surrounding area. The second phase is required except in cases where the entire farm is sited in depths of -20 m mean lower low water (MLLW) or greater. Phase 2 requires the generation of a detailed map beneath the footprint of the lease. The final maps in Phase 2 must show all survey transects and the baseline conditions of NAV in the surveyed area of the proposed farm site. Surveys may be conducted via towed video, remotely operated vehicle, or a dive survey. Video analysis of NAV must be completed by someone qualified to identify the functional groups of key species. A map must be created for each vegetation class observed. Both phases must occur between July 1 and October 1 to target the peak growing season of the majority of local NAV. Contact DNR directly for more information on seaweed farm leases (DNR 2024a).

Product safety regulations

As previously discussed, seaweed is known to accumulate environmental contaminants, such as heavy metals, pharmaceuticals, pathogenic bacteria, and viruses (Banach et al. 2020; Focker et al. 2022). While this bioremediation potential is beneficial for the surrounding environment, it can be problematic when the harvested seaweed is intended for commercial use (Znad et al. 2022). As sites vary, so do the levels and types of contaminants within them. Similarly, regulations for the maximum level of contaminants may be specific to the product use (Lähteenmäki-Uutela et al. 2021). For example, seaweed grown for human consumption, animal feed, and fertilizer may be governed by additional regulations than those grown for use as textiles or biofuel.

Currently, there are no water quality regulations for seaweed aquaculture for human food. However, it is generally recommended to follow DOH processes for shellfish aquaculture if the intention is to grow seaweed for human consumption. The DOH program

monitors and evaluates growing areas using sanitary surveys and assigns one of four classifications—Approved, Conditionally Approved, Restricted, and Prohibited—to tidelands and waters under the National Shellfish Sanitation Plan (DOH n.d.). To varying degrees, the last three classifications limit the use of shellfish from these growing areas based on water quality. These classifications are evaluated annually and change as data prescribes, and classifications are determined based on the accumulation of bacteria in shellfish. This system for determining safe production and consumption of shellfish is robust and could serve as a framework for seaweed aquaculture food products; that said, additional research is needed to incorporate seaweed-specific science into decision-making for siting seaweed aquaculture, which may vary depending on the end use of seaweed (e.g., food vs. nonfood product).

The U.S. has not yet established regulations around safe levels of contaminants for seaweed consumption; however, safe contaminant contents can be compared to U.S. Environmental Protection Agency cancer-screening levels as well as FDA and international guidelines (Hahn et al. 2022). The FDA classifies seaweeds as *generally recognized as safe* as a food additive. Seaweed producers and processors can look to available national and international guidance and resources, such as *Seaweed Food Safety: Comparing Compliance with Preventive Controls for Human Foods and Seafood HACCP* (Ciaramella et al. 2023), *Seaweed Production and Processing in Connecticut: Guide to Understanding and Controlling Potential Food Safety Hazards* (Concepcion et al. 2020), and the FAO and World Health Organization (WHO) *Report of the Expert Meeting on Food Safety for Seaweed: Current Status and Future Perspectives* (FAO and WHO 2022).

Food processing regulations, which address steps such as drying or creating value-added products, may apply to seaweed. Seaweed in its whole form is not regulated as a food product at the federal level (Engle and Stone 2018; Janasie and Nichols 2019). Two federal models are used to regulate seaweed processing in Washington: the Hazard Analysis Critical Control Point (HACCP) plans and the U.S. Food

Safety Modernization Act provisions. Both processes require an internal analysis of potential hazards and a written plan to address identified hazards, such as contaminants introduced during grow-out, harvest, packing, or storage phases (Janasie and Nichols 2019). These requirements only apply if the product is processed, so fresh products sold directly from a farm are exempt. For farms that handle their own processing, a food processor license is required (WSDA [Washington State Department of Agriculture] n.d.). WSDA is the lead state agency for seaweed processing and will provide a Food Processing Plant License and the required subsequent routine facility inspection.

FDA labeling requirements for nutritional facts must be met, which provides honest and accurate labeling of products for consumers. In order to provide accurate nutritional labeling, scientific testing on the nutritional makeup of seaweed products is needed (Good and Jones 2023). Updated in 2016, the Nutrition Facts label requirements for packaged foods are mandated by law and provide guidelines for food labeling and nutrition (FDA n.d.).

Environmental, biosecurity, and genetic diversity policy considerations

For aquaculture industries to develop sustainably, enabling policies and regulations addressing environmental concerns are vital, including concerns such as biosecurity threats, impacts on wild stocks, and genetic diversity (FAO 2013).

WDFW implements biosecurity regulations for Washington's aquaculture industries, including seaweed. As previously discussed, WDFW requires an interstate transport permit for marine plants, which requires WDFW approval to ensure the protection of aquaculture products and native marine plants from disease or pests. It is unlawful to transfer marine plant aquaculture products between any of the following geographic areas without first obtaining a transfer permit: the Columbia River, Pacific Ocean waters, Willapa Harbor, Grays Harbor, and Puget

Sound. No transfer permit is necessary for a transfer that stays within the bounds of these geographic regions (per WAC 220-370-220 [Marine Plant Aquaculture Disease Control 2025] and per WAC 220-340-150 [Unlawful Acts—Permit Required 2025]). Regarding import permits, it is important to note that currently, no out-of-state seaweed hatcheries are approved to import seaweed for aquaculture purposes into Washington. All seaweeds' seed material must be provided by an in-state facility (WDFW n.d.: "Marine Plants (Seaweed)" section). Those looking to complete a marine plant transfer permit will need to submit a Shellfish Transfer Permit application (WDFW n.d.: "Shellfish Transfer Permits" section).

In an effort to protect wild kelp and genetic diversity, DNR developed a sori collection protocol to emphasize sustainable collection practices, maintain genetic diversity, and control the transfer of invasive or pest species and disease. These protocols are required by the State of Washington when operating on SOAL. The protocols vary by species, and each lease agreement provides a list of allowable seaweed species (which currently only includes sugar and bull kelp). Sori cannot be collected without first gaining DNR approval through a sori collection plan. After collecting the sori, leaseholders must resubmit a sori collection plan with updated information so that DNR can track the actual collected materials and locations (DNR 2024b).

As mentioned previously, commercially farmed seaweed in Washington is not permitted to be left in the water after it has developed reproductive material to limit potential impacts to wild stocks while scientists continue to study local kelp genetics. However, some researchers and farmers are interested in the potential benefits of spore overflow from kelp farms to bolster wild kelp beds.

Public perception and social license

A major challenge to the expansion of aquaculture industries can be negative public perceptions of the aquaculture industry and potential impacts to environmental systems and mammals (Knapp and Ru-

bino 2016). Seaweed aquaculture efforts in Washington from the 1970s to 1980s were ultimately halted due to the lack of social license, and as interest has started emerging in Washington again, there have been examples of county-level opposition via the permitting processes (Denkmann and Cowan 2023). Given the novelty of seaweed farming in Washington, social license will most likely be a top consideration for any future potential seaweed farmers (Kim et al. 2019).

Whitmore et al. (2025) suggested gaining public support through trust-building actions prior to beginning the permit application process. Trust-building actions include keeping communication consistent and transparent with stakeholders, taking action to promote distributional and procedural fairness, and making positive impacts on social infrastructure within the host community (Whitmore et al. 2025). When communicating with the public, providing opportunities for informed dialogues on the real risks and impacts is crucial. Additionally, understanding existing perceptions can inform future approaches to public engagement and present an opportunity for further research (Hudson 2016; Froehlich et al. 2017).

In Washington, negative perceptions exist for finfish aquaculture due to past incidents in the state and concerns over impacts to wild salmon species; these sentiments may be less notable for the non-fed species of seaweed (Hudson 2016; Ehrhart and Doerr 2022). There is an opportunity for increased education and outreach regarding aquaculture activities in Washington. WSG is one organization supporting public education and outreach efforts on seaweed aquaculture. WSG is available to answer questions about seaweed aquaculture and share related educational resources and funding opportunities (WSG n.d.). The public has also been informed of seaweed aquaculture activities through news media, which have highlighted WSG, current seaweed farmers, and PSRF (Weinberger 2019; Denkmann and Cowan 2023).

Each potential seaweed farmer's particular challenges will depend on the location and context, so

while gradually gaining rapport with the local community is an important step in the permitting process, it may not fully alleviate or eliminate concerns. A U.S.-focused study by Shaughnessy et al. (2023a) found that positive perceptions and social acceptance correlated with familiarity with marine aquaculture. The study also found that providing marine aquaculture education resulted in an increase in these favorable opinions.

Some seaweed farmers in Washington have taken steps to educate the community, including creating publicly available websites listing the community considerations that went into siting the farm, such as selecting a site that minimizes overlap with NAV and not siting in areas frequented by marine mammals and herring spawning (Vashon Kelp Forest n.d.). They also share information about their farm's guiding principles, goals, and research interests. Transparency is a key component in gaining public trust. Sharing the process of goal setting, planning, and siting is a useful step in building public support, in addition to transparency about active farm management practices such as environmental monitoring efforts (Whitmore et al. 2025).

Washington seaweed community perceptions survey

To better understand community perceptions of seaweed aquaculture in Washington, TNC surveyed WSC members, as well as those who expressed interest or attended the December 2022 WSG Seaweed Knowledge Symposium, about their seaweed-related interests and concerns. Forty-nine people responded, including representatives from the seaweed community such as current and prospective farmers, agency staff, Tribal Nations, academics, NGOs, and coastal residents. A full list of questions is available in this document; see [Appendix A](#).

Respondents felt the most important role for seaweed aquaculture in Washington was the provision of sustainable products and environmental benefits. More specifically, respondents were excited about the ability to grow seaweed with zero inputs while providing potential ecosystem benefits such

as habitat creation, improved water quality, and native kelp restoration.

Some of the key concerns brought up included permitting issues, siting, ecological risks, and impacts to Tribes. Respondents had concerns over regulatory uncertainty and the length of time it takes to get permits and leases. Some respondents worried about Washington stakeholders' limited ability to understand or anticipate negative impacts due to

the early stages of seaweed aquaculture in the region, and some emphasized the importance of thorough permitting and regulatory processes to minimize these risks. (See [Appendix A](#) for a more complete description of the survey questions and results.)



Kelp collection to feed purple sea urchins at Friday Harbor Laboratories (© Morgan Heim)

Section 5: Conclusion & next steps

Seaweed aquaculture in the U.S. has immense potential for both the environment and sustainable livelihoods. Washington has been identified as one of the top marine ecoregions where seaweed aquaculture, when farmed with the right management practices in the right locations, could be environmentally and socially beneficial and economically viable (Theuerkauf et al. 2019). The Washington seaweed aquaculture industry is emerging, and many policy, environmental, market, and social considerations should be explored and prioritized to build a thriving industry that benefits farmers, adjacent industries, the ecosystem, Indigenous communities, coastal communities, and all Washingtonians. Given that the industry has been relatively slow to grow, several challenges have been identified, from limited markets to a lack of upstream and downstream infrastructure to an underdeveloped policy and regulatory environment.

A critical barrier for Washington seaweed farmers—not unique to Washington, but also faced by other U.S. seaweed farmers—is a lack of established markets, or rather a lack of market demand for farmed seaweed at a price acceptable to the farmer. Entering existing markets is incredibly challenging for U.S. seaweed farmers, as they face competition from low-cost wild seaweed harvested domestically and globally, as well as low-cost farmed seaweed imported from well-established international supply chains. Washington seaweed farmers face the difficult task of creating or entering into new markets. Potential market pathways for the Washington farmer include but are not limited to seeking out and developing higher-value niche products, creating markets that can absorb large quantities of biomass, and/or

testing innovative methods to enhance industry and processing efficiencies and lower the cost of seaweed products. Market outreach from state agencies or NGOs, coupled with market pull from private companies, could also help open sales channels and expand opportunities.

While Washington has limited supporting infrastructure for a seaweed aquaculture industry, opportunities do exist through several efforts. PSRF's seed bank efforts have served dual purposes, supporting kelp restoration and aquaculture while pre-



Blue Dot Sea Farms (© Joth Davis)

serving the seeds of declining kelp beds. Washington's relationships and partnerships between industry and restoration experts are unique and should be considered an asset for the industry's emergence.

Washington, similar to many U.S. states, would benefit from an in-depth spatial analysis to better understand the extent of suitable locations in its marine environment. Siting decisions must consider whether specific locations have optimal environmental conditions, meet permit requirements, avoid navigable areas and important fishing areas, and minimize other user conflicts. Another consideration is the potential for new seaweed farms to leverage existing permits, infrastructure, and community acceptance. Permitted shellfish growers looking to diversify their crops may experience easier entry into the seaweed aquaculture industry through seaweed-shellfish co-culture. While a permitting process for in-water seaweed aquaculture does exist, it is not specific to seaweed aquaculture and relies heavily on shellfish aquaculture regulations. The creation of seaweed-specific regulations and forms is needed.

Many Pacific Northwest Tribes and First Nations have engaged in diverse sea gardens and the sus-

tainable harvest of wild seaweed since time immemorial. Some Tribes in Washington have expressed interest in seaweed aquaculture as an economic development strategy that is consistent with cultural and environmental values. At the same time, concerns over large-scale extractive industries infringing on Indigenous rights, access, and well-being have also been expressed. Tribes can be, and are, critical partners and educators in helping the seaweed aquaculture industry meet its restorative potential in Washington and throughout the Pacific Northwest, given their traditional knowledge and seaweed-harvesting expertise. Also, ensuring Tribal interests, rights, and authorities are prioritized in seaweed aquaculture decision-making is key.

Finally, further research is required to inform science-based decision-making, policies, and regulations. Relevant research topics include more localized research on socioeconomic impacts as well as climate, biodiversity, habitat, water quality, and ecosystem effects. This report concludes with potential next steps and research areas to potentially prioritize in the seaweed aquaculture space. As seaweed aquaculture grows in Washington, partnerships among farmers, Tribes, NGOs, industry, researchers, and policymakers will be vital to developing a sustainable and restorative industry.

Potential next steps



Policy

- Develop robust seaweed-specific policies and regulations to safeguard against environmental damage.
- Establish dedicated state and federal funding sources for Indigenous-led seaweed aquaculture to help Tribes build personnel capacity for engaging in seaweed policy and industry when interested.
- Standardize contaminant testing to inform industry, regulators, and consumers of the risks and benefits of seaweed use (Good and Jones 2023).
- Engage in spatial mapping at the local or state level (e.g., aquaculture enterprise zones, aquaculture opportunity zones, approved aquaculture areas, or potential lease sites) to inform the permitting process.
- Encourage public funding to support research and innovation in seaweed farming and to provide farmers with support and training.
- Develop comprehensive permitting tools specifically for seaweed aquaculture to aid in permitting processes.



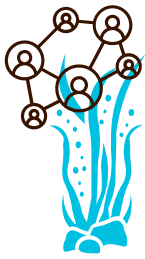
Environmental

- Assess nutrient mitigation benefits to eutrophic waterways and conduct a Washington-specific study on the bioextraction potential of seaweeds in state waters.
- Assess and determine Washington priorities for the cultivation of farmed seaweeds in relation to wild seaweeds—e.g., determining the genetic requirements for spore overflow benefits to wild seaweeds, identifying removal window requirements for specific species to instead reduce spore overflow, and/or developing sterile strains to eliminate the chances for farmed-to-wild gene flow (Coleman et al. 2022).
- Assess the genetic resources of seaweed to develop genetic conservation policies.
- Conduct research on genetic strains that may be resilient to climate impacts for both restoration and restorative aquaculture needs.
- Research how environmental impacts scale with farm size in Washington.
- Conduct a spatial mapping analysis to understand the extent of suitable in-water locations for co-culture.
- Conduct Washington-specific habitat provisioning studies to assess forage, refuge, and reproduction effects of seaweed and gear on forage fish, salmon, eelgrass, and other key species.
- Encourage the development of long-term monitoring of key environmental variables and habitats to track changes and inform appropriate management responses while enabling early detection of any issues (Creighton et al. 2016), with special emphasis on water quality, species assemblages, hydrology, and kelp genetics (Buckner et al. 2023).
- Assess seaweed aquaculture for a nutrient credit program or water-quality trading program to help manage discharge from point sources such as wastewater treatment plants.



Markets

- Establish localized niche markets and processing abilities that serve Washington, such as higher-value products or markets that can absorb large quantities of biomass. Test innovative methods for industry and processing efficiencies to lower the cost of seaweed products.
- Conduct an economic analysis (currently under development by Maritime Blue) and consider the development of processing infrastructure. A biorefinery concept has the potential to extract multiple valuable products for multiple markets at one location.
- Assess the creation of a co-op to increase processing capacity, available infrastructure, community storage space, and the potential for a collective distribution center for kelp grown in Washington waters.
- Engage in portfolio diversification, adding seaweed to existing shellfish farms. Leverage crops with alternating seasons to maximize the marketability/profits of businesses, particularly as seaweed markets develop.
- Educate consumers about seaweed products to help bridge the gap between consumer familiarity with the products and their willingness to try them.
- Encourage and seek out capital investment funding, such as return-seeking investments, grants, equity investments, and/or loans for farm infrastructure and processing.
- Explore the potential and cost benefits of pursuing eco-labeling for seaweed products.
- Develop market assessment tools and models, such as cost-benefit analysis scenarios, to help potential farmers balance environmental and economic risks with the potential benefits of seaweed production (TNC and Bain and Company 2023).



Social

- Assess the emerging industry's socioeconomic benefits and impacts on local and coastal communities.
- Conduct a feasibility analysis to determine the viability of small-scale, Indigenous-led seaweed aquaculture businesses, examining the impacts of different support models for Indigenous communities to pursue seaweed aquaculture, and ensuring Indigenous interests and perceptions are prioritized in decision-making.
- Recognize and address the legitimate concerns of stakeholders and community members.
- Create educational materials on the benefits of consuming seaweed, creating incomes and jobs, supporting livelihoods for Tribes and coastal communities, and maintaining working waterfronts (Knapp and Rubino 2016).
- Encourage industry mentorships and engage in on-farm instruction in better management practices and vocational training for prospective farmers.
- Encourage industry partnerships with researchers and technical college training programs.

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Appendix A

Seaweed Community Survey Report

Monea Kerr, 2023

Introduction

The Nature Conservancy (TNC) is interested in gaining insights into the status of research, policy and management, environmental benefits and impacts, societal implications, market opportunities, and site selection considerations for seaweed aquaculture in Washington state. An important factor in understanding the seaweed industry in Washington is the perspectives of stakeholders (e.g., current and prospective seaweed farmers, scientists, nongovernmental organizations [NGOs]), government agencies, and Tribes. This appendix provides a subset of the Washington seaweed community's responses to questions about the emerging industry. The findings of this survey are intended to identify areas of excitement and concern among the seaweed aquaculture community in Washington.

Methodology

The survey consisted of six structured multiple-choice and fill-in-the-blank questions. It was designed as a one-time snapshot of trends within the sample population, seeking to elicit the current seaweed community's perspectives to know where to focus research, policy, and management efforts in this emerging industry. For the purpose of this study, the *seaweed community* is defined as those who are a part of the Washington Seaweed Collaborative (WSC), coordinated by Washington Sea Grant (WSG), and those who expressed interest in or attended the WSG Seaweed Knowledge Symposium held in December 2022. This group includes individuals from different sectors of the seaweed aquaculture space, including individual producers, market professionals, industry consultants, agency staff (from local, county, state, and federal entities), Tribal members and government staff, NGOs or nonprofits, academia, and coastal residents.

The survey was emailed to the abovementioned groups in April 2022. Forty-nine people responded over three weeks. The survey was conducted entirely online through Google Forms and had no eligibility requirements. A limitation of this survey was that it used a nonrandom sampling method based on a previously compiled list of people who were already interested or involved in the seaweed community.

Each respondent was asked the following:

1. Their affiliation(s).
2. What about the prospect of seaweed aquaculture in Washington most excites or concerns you?
3. What do you feel is most important to consider if the seaweed aquaculture industry grows in Washington?
4. What do you think, if any, are the most important roles seaweed aquaculture can play in Washington?
5. What do you think, if any, are the most important concerns regarding seaweed aquaculture in Washington?
6. What other thoughts do you have about the future of seaweed aquaculture in Washington?

Respondents were alerted at the beginning of the survey that their responses would remain anonymous. For full survey text, see [Appendix B](#).

Results

Question 1: Affiliations

The 49 respondents had the option of selecting all applicable affiliations from a multiple-choice list. The responses revealed 12 seaweed farmers (either prospective or current), seven shellfish farmers (either prospective or current), two individuals associated with seaweed markets, two industry support or consultation professionals, two county or local government staff, seven state agency staff, seven Tribal representatives, five federal agency staff, 11 NGO or nonprofit-sector employees, seven academics, and seven coastal residents. Responses to the “other” category included a finfish farmer, scuba diver, ocean advocate, and public speaker. One person did not list their affiliation. See Figure A-1 for a breakdown of respondents’ affiliations.

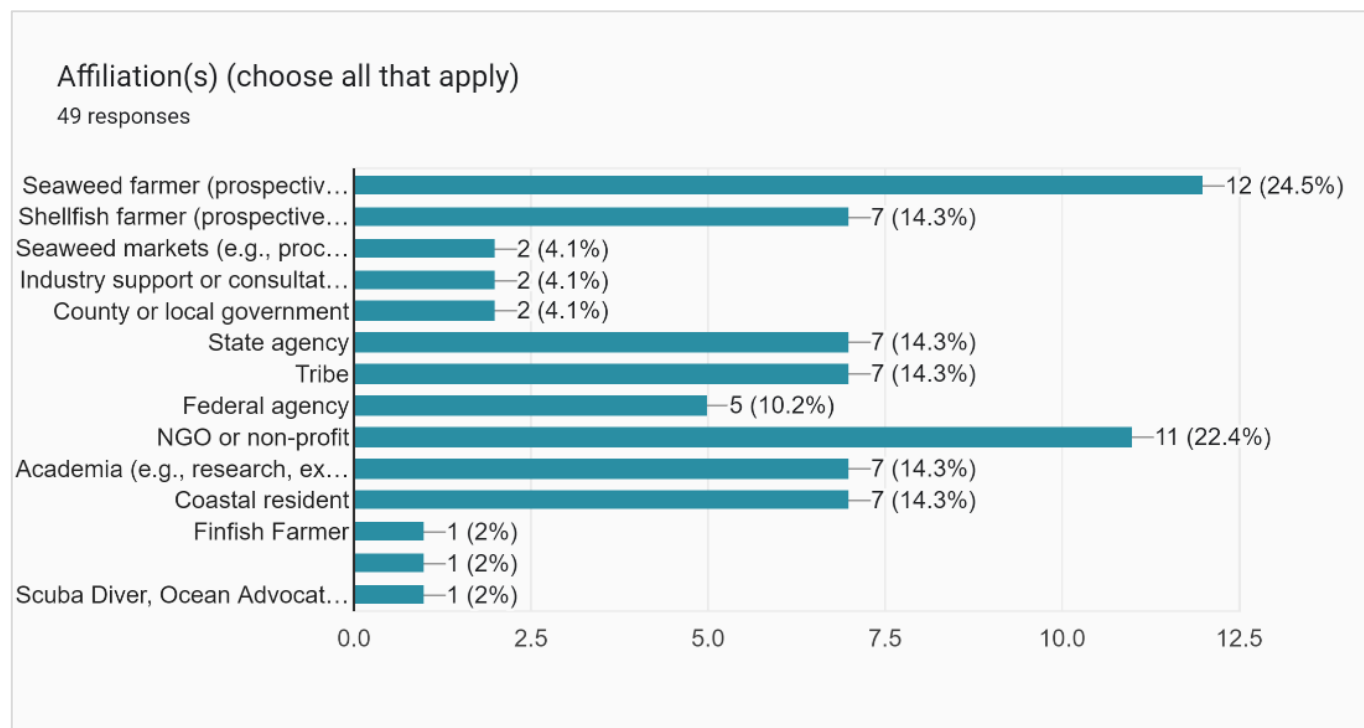


Figure A-1. Respondent affiliations listed by number of individuals and percentage of the overall survey pool.

Question 2: What about the prospect of seaweed aquaculture in Washington most concerns or excites you?

When considering concerns and excitement about seaweed aquaculture in Washington, respondents brought up the topics of permits and regulations, ecosystem services and impacts, and social aspects of the emerging industry.

Permits and regulations

Respondents had concerns over regulatory uncertainty and the permitting process. Specifically, the time required to obtain permits and leases, as well as the need to streamline permit reviews while still accounting for environmental protection. The respondents recognized that to be successful, the industry would need support from state and federal agencies.

Ecosystem services and impacts

Most respondents felt that seaweed aquaculture is a positive, beneficial use of the marine ecosystem. Kelp farming could provide ecosystem services, such as carbon sequestration and habitat benefits, while requiring zero inputs for farming, enabling the production of a sustainable product. Respondents were also interested in the potential of kelp farming to contribute to native kelp bed restoration and kelp recovery initiatives. On the other hand, there were accompanying concerns around the potential impacts of farming kelp on naturally occurring kelp beds and the local environment. Concern focused on the uniqueness of the Salish Sea ecology and the need to carefully evaluate potential ecological impacts, such as eutrophication, introduced species, plastic pollution, disease, genetic interactions with wild seaweeds, marine mammal and other marine species interactions, restrictions on other marine uses, and damage to the seafloor from anchoring. Questions also arose about whether carbon sequestration benefits have been exaggerated.

At a higher level, respondents stated that there was a need to proceed with some caution and share sound science when communicating about farming projects. There was also a need to understand the ecosystem benefits and impacts of different production scales and farm sizes. For instance, there was interest in testing assumptions about the ecological benefits and risks of small (< 15 ac) seaweed farms, which are the farm sizes currently being considered in Washington.

Societal aspects

Societal benefits, including workforce development opportunities and food production, were mentioned. Seaweed aquaculture was seen as a potential small-scale industry for coastal communities, providing food sovereignty and security, the development of new local products, the creation and/or expansion of jobs, opportunities for women, and support for strong rural livelihoods. Many respondents were excited about helping a budding industry grow and become sustainable, with the potential for positive externalities. They expressed excitement about future projects led by Tribes that offer a connection to water in the face of declining fisheries. Another respondent was excited about the potential for high-value, small-volume, niche products sourced from species best suited to smaller grow operations in the Salish Sea. However, it was noted that Washington industry's undeveloped processing capacity and market pathways were areas of concern, as this underdevelopment would make it difficult to realize economic benefits - especially when competing with established and robust Asian markets. Respondents also pointed out the need to acknowledge how little is known about the health risks of consuming seaweeds produced in the Salish Sea (e.g., toxins and heavy metals).

Finally, community acceptance of aquaculture was of concern. With shoreline areas heavily populated in many parts of the state, it could be difficult to expand aquaculture operations due to the lack of marine space and shoreline homeowners' NIMBY (not in my backyard) mentality about seaweed aquaculture. There was also a stated need for community outreach, as well as seaweed farm accountability to local communities and Tribes. While some Tribes are interested in seaweed aquaculture, others have different priorities and are not interested in farming activities that overlap with Tribal fishing grounds.

Question 3: What do you feel is most important to consider if the seaweed aquaculture industry grows in Washington?

Similar themes emerged in Question 3 as in Question 2, including a need to consider regulatory hurdles, societal concerns, ecological impacts, and markets.

Regulatory hurdles

Within the regulatory environment, reducing bureaucracy and red tape was an important enabling condition for the industry. One respondent noted that the regulatory framework needs updating, and some mentioned

a need for a less stringent permitting process. On the other hand, some respondents thought more regulation was needed. Farm design factors were identified as important—such as careful siting, spatial planning, and the designation of a specific subset of sites as potential farming sites, rather than opportunistic and scattered permit applications. One respondent emphasized the importance of developing the industry conservatively, using an adaptive management framework and planned research and monitoring, to ensure environmental sustainability.

Societal concerns

Respondents mentioned that the accessibility of seaweed aquaculture should be considered. People outside of privileged groups should be able to succeed in getting leases and permits. One potential solution mentioned was supporting people without prior experience in joining the industry.

Centering Indigenous culture was brought up as a consideration, including prioritizing Tribal treaty rights, knowledge, and needs. Respondents noted that seaweed is an important traditional food and that Indigenous voices should be included at the table when discussing seaweed aquaculture. Having Tribes lead the way or be involved as partners was identified as necessary for industry success. Furthermore, respondents said it was important for entrants not to colonize the surface waters and to consider the location of seaweed aquaculture in the context of Tribal sovereignty and access to Usual and Accustomed (U&A) fishing grounds.

Ecological impacts

Excitement was expressed over farming native species and the potential to contribute to kelp forest restoration and ecosystem services. The benefits for habitat and water quality were deemed important, as was expanding knowledge of the interactions between kelp farms and the surrounding ecosystem. Some respondents were interested in kelp farming for restoration as well as harvesting.

Respondents also mentioned the importance of objectively considering the unintended ecological consequences of seaweed aquaculture and ensuring the risks are weighed against the benefits. For example, concerns over growing practices were expressed; respondents mentioned the need to focus on multiple native species in state waters rather than creating a monocrop, controlling the spread of invasive species, avoiding the use of chemicals or excess nutrients in the system to increase productivity, and avoiding the use of genetic modification. Other ecological impacts were mentioned, including impacts on species listed under the U.S. Endangered Species Act and other sensitive species. There were concerns expressed about appropriately siting to reduce the risk of large whale entanglements; establishing siting and infrastructure criteria to avoid or minimize unintended consequences for natural systems; understanding scalable impacts on natural habitat; establishing proper environmental regulatory standards; and using ecologically responsible best practices for cultivation and cultivar development.

Markets

Some respondents echoed concerns over market conditions in Washington and a need to develop processing facilities, affordable products, and domestic markets for seaweed and value-added products. Respondents also mentioned the need for growth in adjacent industries, including additional sales support, greater connections with researchers, and more manufacturers in adjacent industries (e.g., fertilizer producers). If the industry grew and stabilized, jobs could be created, and sustainable development and growing research opportunities could be attained. Carbon markets and co-culture with shellfish were mentioned as two ways to increase the economy around seaweed farming; however, support (financial and technical) would be needed to pursue these pathways.

Question 4: *What do you think, if any, are the most important roles seaweed aquaculture can play in Washington? (Choose your top 3 ranked in order of importance.)*

When asked what respondents thought the most important roles were that seaweed aquaculture could play in Washington, the role ranked as both “most important” and “second most important” was the opportunity to develop sustainable foods, agricultural amendments, or other products (Figure A-2). The “third most important” role of seaweed aquaculture was its potential to provide local economic opportunities and jobs. This analysis was not tested for significance, so the findings are only intended to show respondent trends.

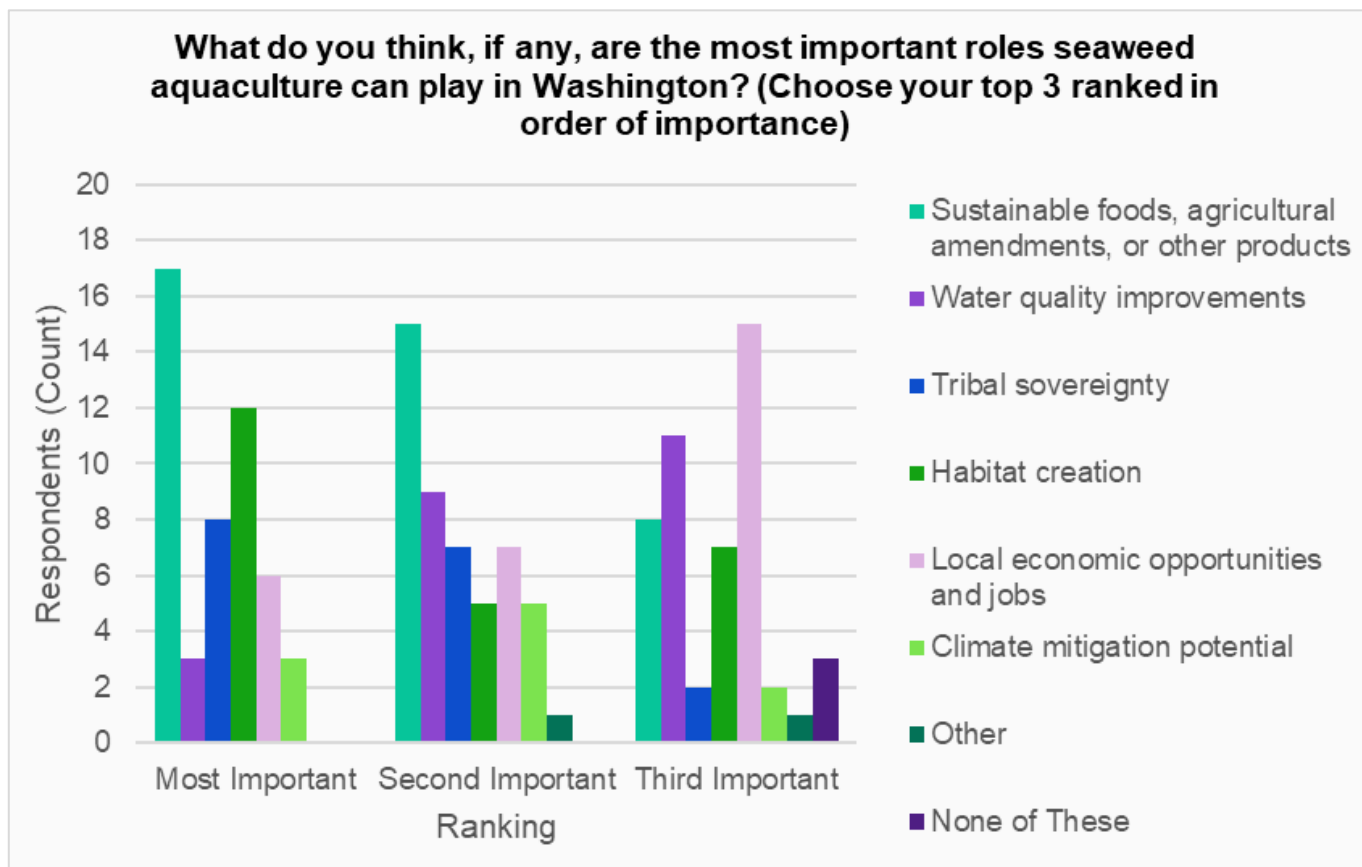


Figure A-2. The distribution of responses to the question “What do you think, if any, are the most important roles seaweed aquaculture can play in Washington?”

Question 5: *What do you think, if any, are the most important concerns regarding seaweed aquaculture in Washington? (Choose your top 3 ranked in order of importance.)*

Respondents ranked ecosystem impacts and permitting issues as the “most important” concerns regarding seaweed aquaculture in Washington (Figure A-3). The “second most important” concern was site location (e.g., conducting effective siting for farm success and avoiding impacts). Ecosystem impacts, considerations of kelp genetics, and permitting were ranked as the “third most important” concerns.

Those who selected “other” mentioned concerns over how to sustain a kelp farm with no buyers, potential large whale and other marine mammal entanglement, market stability, and local community and public impacts. One respondent mentioned the need for control and oversight, building public trust in seaweed aquaculture, a robust public process, accountability, and management to mitigate environmental degradation in

public waters. Again, it is important to note that this analysis was not tested for significance, so the findings described here are only intended to show respondent trends.

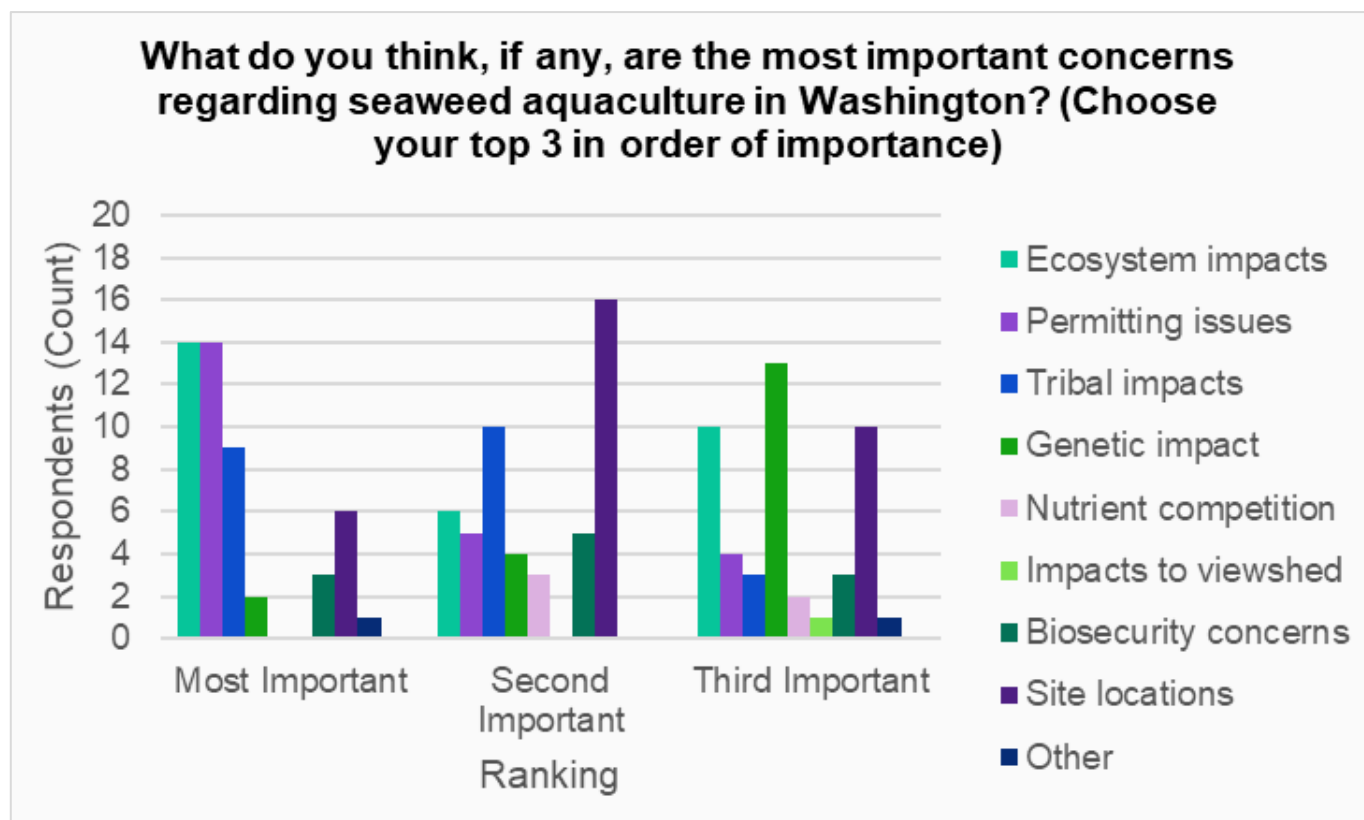


Figure A-3. The distribution of responses to the question “What do you think, if any, are the most important concerns regarding seaweed aquaculture in Washington?”

Question 6: What other thoughts do you have about the future of seaweed aquaculture in Washington?

The survey’s final open-ended question allowed respondents to provide any other thoughts about the future of the seaweed aquaculture industry in Washington. The following lists summarize the responses, organized by topic:

Environmental benefits

- There is a need for state or federal funding to support seaweed farms as habitat.
- Seaweed farms could be at every effluent release point on the coast [supporting improvements in water quality].
- There is hope that seaweed aquaculture can thrive and be incorporated into existing aquaculture projects to limit the expansion of their footprint and potentially offer ecosystem benefits.

Environmental impacts and concerns

- Seaweed aquaculture could increase microplastics and interact with both wild-harvested and farmed seaweed.
- It is important to learn from mistakes from other regions, such as the unsightly division of waters, disease, invasives, trash, the need for management and enforcement, and the impact on eelgrass and existing kelp.

- The Salish Sea ecosystem has experienced degradation from salmon hatcheries. This issue should not be replicated with another species group, and seaweed aquaculture should move forward cautiously and with sound science.
- Eelgrass habitat should be considered when siting kelp aquaculture.

Public outreach and education

- There is a need for education and awareness to help consumers understand how and where to purchase and use seaweed—and why they should.
- There is a need to help the public see seaweed as a positive, which is best done through food.

Tribal partnerships

- Create synergy with institutions and Tribes when considering kelp aquaculture.
- There is a desire to understand the threats that seaweed aquaculture poses to Tribal fishing so that prospective seaweed farmers can address these concerns.

Markets

- There is a desire to someday see Washington producing all the seaweed it consumes.
- Local markets for seaweed products are of interest to avoid exports, with the goal of ensuring food products are affordable and accessible, and not just in restaurants.
- There is a need to market both seaweed and shellfish as approachable, educational, family-oriented, and affordable.
- Respondents were encouraged that people are buying seaweed products, and there is a need to sustain the industry by maintaining a consistent supply for buyers.
- There is a need for a framework or strategic plan with buy-in from the private sector, Tribes, state and federal agencies, and NGOs, including a shared premise that the private sector both adds funding and depends on a credible story about environmental benefits.
- The respondents expressed concerns that there was more interest in production than consumption and that the returns on seaweed aquaculture may not be significant.
- There is a fear that a boom-and-bust scenario could occur. Similarly, marginalized groups may be left out due to a lack of capital and low profitability, which could discourage interest from these groups, as they need to advance materially.
- The demand for kelp in the near future may not be sufficient to support large-scale production of related products.

Policy and regulations

- Not much is known about farming seaweed in Washington, so there are more questions than answers.
- Having patience with local, state, and federal agencies while they tackle these questions would be appreciated.

Research

- There is hope that seaweed aquaculture can start at a small scale with applied research.
- Support for comprehensive research on the social and environmental factors of seaweed aquaculture is needed to put a system in place that works for the environment and people—one that includes businesses, the public, and Tribes.
- There is a lack of and a need for social science in aquaculture generally. The issues of ocean grabbing, the exclusion of marginalized ocean users, and blue justice were noted.

The future of the industry

- There is excitement for seaweed aquaculture in Washington. Respondents hoped that learnings from individuals and entities farming seaweed in British Columbia and Alaska could be taken into account.
- While kelp farms may not have an appreciable impact on global carbon dioxide (CO₂) sequestration, they may locally ameliorate ocean acidification impacts, create/bolster habitats, and strengthen the economy through additional food security.
- There is hope that the newness and potential do not overshadow the need to remain critical and realistic when moving forward with seaweed aquaculture.

Conclusion

This survey collected high-level perspectives about the emerging seaweed aquaculture community in Washington state. The responses indicated awareness of both the potentially positive and negative outcomes of seaweed aquaculture for people and the environment, including considerations of ecological benefits and impacts, research gaps, community outreach, regulatory hurdles, and market opportunities. Synergies in stakeholders' interests can be used to identify where to put energy, resources, and guidance for future areas of research.

Appendix B

Seaweed Community Survey

The following survey questions will be analyzed as part of a Washington seaweed aquaculture situation analysis report conducted by Monea Kerr (Washington Sea Grant Marc Hershman Marine Policy Fellow at The Nature Conservancy), who will examine the status of the state's seaweed research and industry and considerations for future development of seaweed aquaculture. Your responses will be kept anonymous.

1. Affiliation(s). (Choose all that apply.)
 - 1.1. Seaweed farmer (prospective or current)
 - 1.2. Shellfish farmer (prospective or current)
 - 1.3. Seaweed markets (e.g., processor, culinary)
 - 1.4. Industry support or consultation (e.g., legal, environmental)
 - 1.5. County or local government
 - 1.6. State agency
 - 1.7. Tribe
 - 1.8. Federal agency
 - 1.9. NGO or nonprofit
 - 1.10. Academia (e.g., research, extension, student)
 - 1.11. Coastal resident
 - 1.12. Other (with a fill-in-the-blank field)
2. What about the prospect of seaweed aquaculture in Washington most excites or concerns you?
3. What do you feel is most important to consider if the seaweed aquaculture industry grows in Washington?
4. What do you think, if any, are the most important roles seaweed aquaculture can play in Washington? (Choose your top 3 ranked in order of importance.)
 - 4.1. Sustainable foods, agricultural amendments, or other products
 - 4.2. Water quality improvements
 - 4.3. Habitat creation
 - 4.4. Climate mitigation potential
 - 4.5. Tribal sovereignty
 - 4.6. Local economic opportunities and jobs
 - 4.7. Other
 - 4.8. None of these

5. What do you think, if any, are the most important concerns regarding seaweed aquaculture in Washington? (Choose your top 3 ranked in order of importance.)
- 5.1. Ecosystem impacts
 - 5.2. Genetic impacts
 - 5.3. Biosecurity concerns
 - 5.4. Permitting issues
 - 5.5. Nutrient competition
 - 5.6. Site locations
 - 5.7. Tribal impacts
 - 5.8. Impacts to viewshed
 - 5.9. Other
 - 5.10. None of these
6. What other thoughts do you have about the future of seaweed aquaculture in Washington?



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