Removal, stabilization, and market pathways for a nuisance seaweed in Puget Sound: A Resource for Shellfish Farmers and Researchers on the causes, removal, and uses of green tides caused by *Ulva* spp.

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PUGET SOUND
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Summary

Ulva, a green (Chlorophyta), marine macroalgae commonly known as ‘sea lettuce’, has a propensity to cause harmful blooms, called green tides, which are becoming a more common and intense phenomena both locally in Washington state and globally, as a growing human population increases coastal nutrient inputs and impacts from climate change create prime *Ulva* growing conditions. Here in Washington, green tides are currently a nuisance and potential threat to the local shellfish aquaculture industry as the seaweed fouls farm gear, smothers shellfish, and may negatively alter water quality when it decomposes. Instead of the current common practice of disposing of *Ulva* in the water or on the beach, what if it could be marketed as a useful product, turning that nuisance into something valuable? Here we show why removing nuisance seaweed may be a beneficial farm practice, that current regulations allow for legal harvest, that *Ulva* can be mechanically removed effectively, and stabilized as a marketable product. A particularly obvious market is that of soil amendments. Seaweed has been a common ingredient to build and improve agricultural soils for millennia. Shellfish farmers who are experiencing the impacts from increased nutrient inputs to local marine waters may be well served connecting with their upland, neighboring growers (farmers and gardeners) who are searching for local, sustainable, and regenerative ways to improve their soils. While there are still a lot of questions around *Ulva*’s presence, impact and marketability, it is clear that sea lettuce can be more than a nuisance, and that there is a local desire to connect sea and land, collaboratively improve water quality, support sustainable local agriculture, and close an important local nutrient loop.

Table of Contents

1.0 Feeling Green: What we know about 'Green Tides'.....4
1.1 Global and Local Phenomena..... 4
1.2 Causes of Green Tides.....5
1.3 Description of Ulva.....7
(a) Species & Morphologies.....8
(b) Habitat.....8
(c) Lifecycle.....8
1.4 A compounding problem on shellfish farms..... 9
2.0 From Sea to Land: How to remove and process *Ulva* for terrestrial uses..... 12
2.1 Seaweed Removal..... 13
(a) Manual Removal.....14
(b) Mechanical Removal..... 16
i.) Floating Pump and Venturi Suction System.....16
ii.) How to Use.....17
2.2 Stabilization and Processing.....21
2.3 Dewatering..... 22
2.4 Drying..... 24
(a) Passive Drying.....25
(b) Active Drying..... 26
(c) Challenges.....26
2.5 Mulching & Pelletizing.....27
2.6 Fermentation.....29
3.0 How does your garden grow? *Ulva* as a Soil Amendment..... 32
3.1 Comparative Nutrients..... 32
(a) Nitrogen - Phosphorus - Potassium (NPK).....33
(b) Secondary Nutrients and Micronutrients..... 34
(c) Heavy Metals.....36
(d) Salt Content.....37
3.2 Garden Performance..... 38
3.3 Upland Connections.....41
(a) Farm to Farm.....41
(b) Farm to Community.....42
(c) Work Parties..... 43
3.4 Innovative Connections..... 43
Appendix A: Washington DNR Fact Seaweed Harvest Factsheet.....51
Appendix B: Soil and Water Salinity Comparisons.....52
Appendix C: Ulva Nutrient Data..... 53
Appendix D: Ulva Heavy Metal Data..... 54
Appendix E: Ulva's Impact on Plant Growth.....55
Appendix F: Heavy Metal Comparisons..... 57

1.0 Feeling Green: What we know about ‘Green Tides’



Figure 1: *Image of filamentous Ulva covering geoduck tubes at a shellfish farm in Washington (photo credit: Bill Dewey).*

1.1 Global and Local Phenomena

Key Takeaways

- Green Tides are an overgrowth or ‘bloom’ of green macroalgae.
- They are usually composed of a single species in the genus *Ulva*.
- Green tides are a global phenomenon and becoming more frequent.
- Green tides are increasing due to impacts from climate change and human activity.
- Green tides can be correlated with high inputs of terrestrial nutrients.
- Within Puget Sound, Washington, USA, green tides commonly occur in shallow embayments and on commercial shellfish farms.

Green tides are a seasonal overgrowth, or a ‘bloom’ of marine green macroalgae (Chlorophyta, typically from the genus *Ulva**), that occur globally in temperate marine waters (Figure 1). While there are differences in how they form, what they look like, and their fate, they all have similar causes and can negatively impact the intertidal zones and shorelines where they occur. In some areas, green tides have been materializing for decades, but are becoming more

widespread and more frequent[1]. Their increasing occurrence is propelled by a growing intensity of human activity due to population growth, as well as climate change[1]. Areas that consistently experienced large green tide events are located in coastal areas adjacent to large human population centers, such as Brittany, France; Shandong, China; and Jiangsu, China[1].

Within Puget Sound, an estuarine fjord in Washington state with a large population center, green tides are an emerging concern, though still far from the intensity of large green tides elsewhere. However, the conditions that favor green tides, such as increases in terrestrial nutrient inputs, are growing along with the local human population in the Puget Sound area [2]. Washington state continues its efforts to reduce nitrogen inputs into state waters, mainly through the construction and improvement of wastewater treatment plants, which are the largest sources of excess nitrogen.

*We should note that in Puget Sound that *Ulvaria*, a different genus but relative of *Ulva* also has bloom-forming capabilities[5].

1.2 Causes of Green Tides

Key Takeaways

- *Ulva* is a naturally occurring species (i.e. it's non-invasive) but can form blooms due to changes in water conditions.
- *Ulva* growth is nitrogen limited, i.e. increasing access to nitrogen increases *Ulva* growth.
- Nitrogen concentrations in Puget Sound are naturally high.
- Sudden, large terrestrial inputs of nitrogen provide the conditions for rapid *Ulva* growth.
- Human sources of increased nitrogen input can come from agricultural runoff, leaks from septic tanks, waste water treatment plant outflows, and increased erosion.

The anecdotal increase in green tide occurrence and the measured change in water conditions that favor *Ulva* growth have piqued regional interest and amplified the desire to better understand the local drivers and impacts of the green tide phenomenon. *Ulva* is opportunistic and can grow in a large range of water conditions[3]. While it can be sparse and grow slowly in poor to moderate growing conditions, once conditions become favorable it can grow rapidly. In good conditions, *U. prolifera* can have a daily twofold increase and another east Asia species, *U. meridionalis*, can have a fourfold daily growth rate[4]. *Ulva* needs the same basic things that all macroalgae need to grow - sunlight, water, air, and nutrients - and usually has a growing cycle that matches with sunlight availability[5], with growth rates peaking during the longest days of the year. Throughout the world, *Ulva* growth has been found to be nitrogen limited and the addition of sufficient nitrogen is the usual factor determining whether *Ulva* will grow rapidly and cause a green tide[6]. This has also been found to be true in Puget Sound[5].

Puget Sound has naturally high nitrogen concentrations in its marine waters due to the intrusion of upwelled waters from the Washington coast[7]. These bring nitrogen-rich waters from the seafloor to the surface and then into the inland waters, where they mix with freshwater inputs carrying terrestrially-derived nitrogen from the surrounding watershed. While nitrogen levels are naturally high in Puget Sound, they are still relatively low in concentration when compared to pulses of human-caused terrestrial inputs[7]. Human-caused sources of nitrogen input can contribute doses of high concentrations of nitrogen to the nearshore environment. If these inputs occur during late spring and summer months, when sunlight levels and water temperatures are higher and natural nitrogen levels from upwelling and river inputs are waning, they can cause *Ulva* to opportunistically grow rapidly into green tides[5,7]. The human population in the Puget Sound area is expected to increase by over 1.8 million by 2050, leading to the prediction of a 40% human-derived nitrogen load increase if wastewater treatment (overflows are the largest contributor of nitrogen inputs) management remains the same[2].

*Nitrogen load = nitrogen concentration x flow

Nitrogen levels in Puget Sound's water are geographically variable[7] (Table 1). Natural variability and proximity to various human activities will change the local nitrogen load in watersheds, the frequency of green tides, and options for reducing nutrient inputs*. Since rapid *Ulva* growth is mostly driven by nitrogen availability derived from terrestrial sources, reducing those inputs may decrease the occurrence of blooms. Depending on the watershed, decreasing nutrient input could look different from one place to the next. These could include making improvements to wastewater treatment plants to prevent nitrogen-rich discharge[8], community campaigns to get homeowners to check and repair septic tanks, or conservation districts helping farmers to plan out strategies to reduce fertilizer and livestock waste runoff (Table 1). At this time it is hard to predict green tides in Puget Sound. They can occur suddenly and increases in terrestrial nutrient input is almost always associated in some way, perhaps revealing green tides as an indicator of changes in coastal water quality

*For example, Henderson Inlet historically has one of the highest concentrations of nitrogen for an embayment in the south Puget Sound region[7]. This is because its watershed lacks a water source located in the mountains, which usually dilutes terrestrial nitrogen inputs from snow melt and increased mountain precipitation[7].

Table 1: *There are several WA state supported resources accessible to the public on local water quality and nitrogen in Washington's marine waters.*

Site	Description
Puget Sound Nutrient Source Reduction Project: Salish Sea Model Results	Interactive map displaying water quality data for the Salish Sea relating nutrient inputs with low dissolved oxygen
Nitrogen in Puget Sound	Story Map describing the sources of nitrogen into Puget Sound
Reducing Nutrients in Puget Sound	Site listing information and tools on nutrient reduction in Puget Sound
WA DOH Commercial Shellfish Map Viewer	Site showing commercial shellfish growing area openings and closings
Voluntary Clean Water Guidance for Agriculture	Info on the Dept. of Ecology's progress on providing nutrient reducing guidance to terrestrial farmers

1.3 Description of *Ulva*



Figure 2: *(Left) bladed form of Ulva in Hood Canal (photo credit: Erick Dowell). (Right) filamentous form of Ulva in Samish Bay (photo credit: Emily Buckner)*

Key Takeaways

- The *Ulva* genus is found along most of the world's shores.
- There two main morphologies: blade-like and filamentous, both can form green tides.
- *Ulva* grows in the intertidal and subtidal and across a range of substrates, temperatures, and salinities.
- *Ulva* can reproduce from cuttings or torn off pieces that are detached and each piece can grow and reproduce while free-floating.

(a) Species & Morphologies

There are around 128 known species in the *Ulva* genus, 15 of which can be found in the Pacific Northwest[3]. Among the variety of *Ulva* species, they can be divided into two distinct morphological groups (Figure 2) - bladed (8 species, e.g *U.* 'lactuca', *U. rigida*, *U. stenophylla*, *U. lobata*, *U. californica* and *U. taeniata)* and cylindrical/filamentous morphologies (7 species, e.g. *U. intestinalis*, *U. compressa*, and *U. linza)*[3]. Species of both shapes of *Ulva* can bloom to form green tides and both forms can be found in the waters of Washington state. However it is very difficult to differentiate *Ulva* at a species level without the aid of a microscope or genetic analyses. As noted above, local macroalgae blooms can be formed by another genus as well - *Ulvaria*[9]. This genus is related to *Ulva*, appears very similar, and also has a global distribution. The key difference is that *Ulvaria* spp. blades are made of a single layer of cells whereas *Ulva* is made of two layers of cells. *Ulvaria* also produces dopamine, a unique feature among macroalgae[3]. The two species found in the Pacific Northwest are *Ulvaria splendens* and *Ulvaria obscura*[3].

(b) Habitat

Ulva can grow in a wide variety of intertidal and subtidal habitats[3], free-floating or growing on a variety of natural or manmade substrates.They can grow in a wide range of water temperatures and salinities including very low salinity water in estuarine environments[3]. This wide range of habitats is true for both morphologies and for some species their morphology might change in response to changes in salinity[3]. Temperature and sunlight can have effects on reproduction and growth rates, but the largest factor for successful growth and reproduction is nutrient availability[10]. The other bloom-forming genus in the Pacific Northwest, *Ulvaria*, is usually found deeper than *Ulva*, often predominanting in the subtidal zone[9].

(c) Lifecycle

Ulva has a biphasic (two-stage) lifecycle that is isomorphic (both stages look the same)[11]. One stage is a gametophyte that is haploid and produces gametes. These fuse to form the zygote and grow into the diploid sporophyte stage. The sporophyte stage produces spores that develop into the gametophytes[3]. Reproduction happens at the margins of the blade or the ends of the filaments[11], with a tell-tale of a yellowish-brown color along the blade edges[3]. These

reproductive margins can sometimes turn white after spores or gametes have been released[3]. *Ulva* can also reproduce vegetatively* if they become detached from their holdfasts or portions of them rip off[11]. Studies have shown that increases in temperature and fragmenting *Ulva* can increase the reproductive response, while decreases in temperature and dehydration decrease reproductive response[12]. Also, higher nitrogen levels correlate with higher fragmentation rates in *Ulvaria* and enables *Ulva* to create more antiherbivory and antioxidant compounds thereby increasing net growth rates and the possibility of a green tide forming[5].

*Vegetative reproduction is where a fragment or a cutting of a plant (or macroalgae) will grow into a genetically identical clone of the original organism.

1.4 A compounding problem on shellfish farms



Figure 3: *Bladed Ulva covering geoduck tubes at a shellfish farm in Washington (photo credit: Erick Dowell)*

Key Takeaways

- Large green tides (i.e. excess seaweed) can negatively affect marine and coastal ecosystems.
- Green tides can foul gear, infrastructure, vessels, and beaches, negatively impacting maritime industries and coastal tourism.
- *Ulva* and *Ulvaria* species produce allelopathic compounds that have been shown to harm shellfish larvae, fish larvae, other macroalgae, and marine plants.
- Seaweed decomposition decreases dissolved oxygen and acidifies local waters, which can be harmful to shellfish and intertidal organisms.
- Masses of *Ulva* can release toxic and flammable hydrogen sulfide (H_2S).
- Green tides change the water quality in ways that might benefit future green tides.

Green tides can foul in-water gear (Figure 3), infrastructure, vessels, and beaches, increasing labor and costs incurred by removing and disposing of the green tides that affect maritime businesses, local municipalities and coastal recreation. Economic losses to shellfish farms and local fisheries could also come from water chemistry and physical changes brought on by green tides. Large quantities of *Ulva* can smother sessile marine and intertidal organisms by blocking water flow, altering sediment transport, and sunlight, negatively impacting shellfish farms (Figure 3) and nearshore ecosystems important to local commercial fisheries[13, 14, 15, 16, 17]. The rapid growth of *Ulva* can also deny essential nutrients like nitrogen or phosphorus from other marine organisms[18]. Once green tides start to decompose they create harmful water conditions by removing oxygen and lowering the pH[19]. Its decomposition also has effects if piled on the shore, as it can release toxic hydrogen sulfide (H_2S)[20, 21]. Several animal and one human death are attributed to high H_2S concentrations on beaches experiencing green tides events in northern France[22]. Green tides can further negatively change the water quality by releasing compounds that have been shown to be harmful to larvae of many commercially important species including: Pacific oysters (*Crassostrea gigas*)[9, 23], eastern oyster (*Crassostrea virginica*)[24], white winter flounder (*Pseudopleuronectes americanus*)[25], green sea urchin (*Strongylocentrotus droebachiensis*)[27], blue crab (*Callinectes sapidus*)[26], Dungeness crab (*Metacarcinus magister*)[28] and purple sea urchin (*Strongylocentrotus purpuratus*)[29]. Drastic changes in water quality conditions brought on by green tides also change the nearby planktonic ecology which could favor increased concentrations of Harmful Algal Bloom-forming planktonic species[19] as well as favor the growth of bloom-forming species of *Ulva* thus supporting a positive feedback loop that increases the chances for green tides in the future[30]. There have been some studies studying the loss of revenue from reduced tourism in other coastal areas affected by green tides, but more studies are needed to investigate the economic

impacts from reduced growth and mortalities of shellfish on farms, especially locally, to show a more complete picture of local economic impacts.

Although green tides negatively affect coastal ecosystems and coastal economies, *Ulva* is a native species that does play an important role in the ecosystem and at appropriate growth rates can benefit shellfish farms. *Ulva*, while alive, produces oxygen during the day and raises the pH, both of which are beneficial to shellfish. Detritus from *Ulva* as well as its spores and gametes are a potential food source for filter-feeding shellfish. *Ulva* mats may protect shellfish from extreme temperatures, desiccation and potential predation at low tide[31].

Locally, some shellfish farmers do remove *Ulva* from farm gear (we estimate that farms may see accumulations of ~48,000 kg of total wet *Ulva* biomass or around 4.3 kg/m^2) but it is usually piled on the nearby beach or left to drift with the incoming tide (PSRF, pers. comm., 2025). Since *Ulva*'s lifecycle allows it to continue to grow and reproduce while drifting and decomposing beach *Ulva* can release all of its nutrients back into the water wholesale removal may be the best way to combat the negative impacts of green tides on commercial shellfish farms. If this is the case, how can Ulva be removed at scale and where should it go? And how does a farmer make this practice economical? We explore these questions and ideas below!

2.0 From Sea to Land: How to remove and process *Ulva* for terrestrial uses

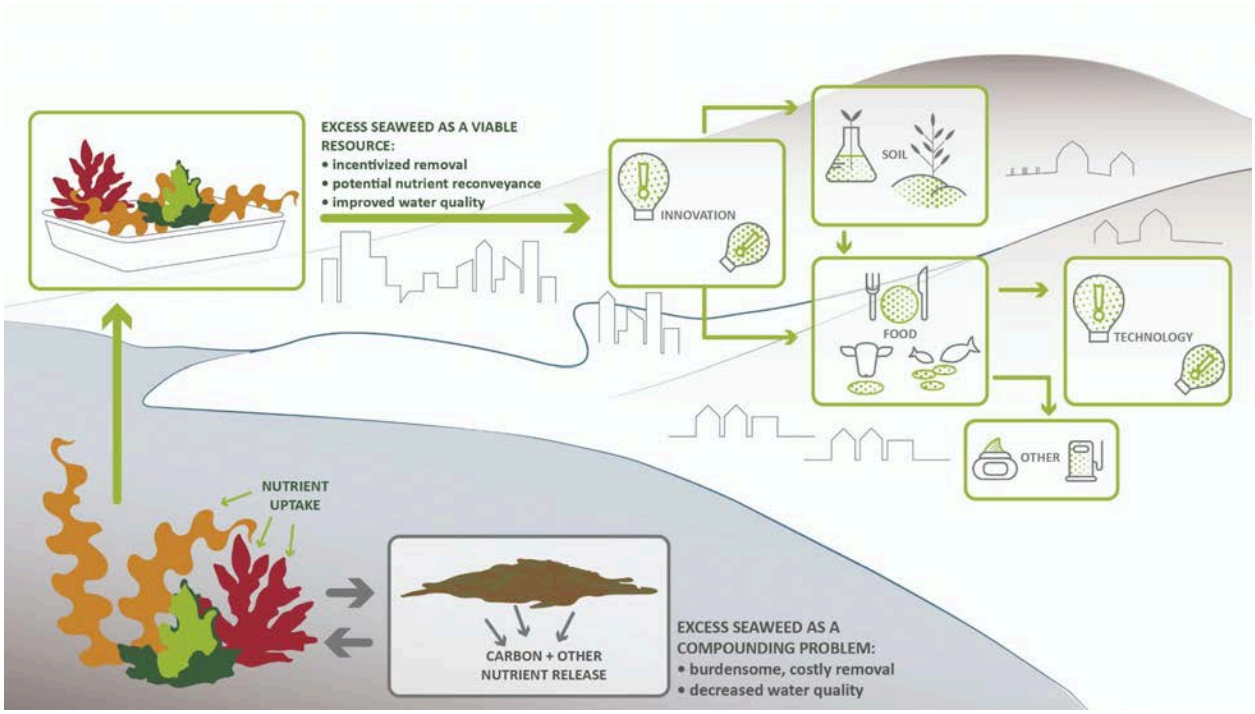


Figure 4: *Concept map of nuisance seaweed removal to market pathway (credit: Hannah Garfield)*

Key Takeaways

- Seaweed has been used globally for millennia as a soil amendment and soil builder.
- Seaweed absorbs key nutrients from seawater that are important for plant growth.
- *Ulva* is absorbing excess nutrients on shellfish farms but its overgrowth is becoming a costly nuisance.
- *Ulva* as a soil amendment could be another avenue for marine nutrients to return upland like salmon.

Humans have been using seaweed for millennia. It has been a food source, feed for livestock,and soil amendment[32]. Coastal macroalgae absorb a mixture of marine-derived and terrestrial-derived nutrients making it a great source of primary and secondary plant nutrients.

Using seaweed as a soil amendment is gaining a resurgence with commercially available and processed seaweed products in the form of meal, liquid fertilizers, and foliar sprays. Using a nuisance overgrowth of seaweed to provide nutrients to nearby agricultural soils, often depleted of important nutrients, offers an opportunity for a regenerative practice (Figure 4). Green tides are often created or exacerbated by agricultural fertilizers washed away by rain and irrigation, therefore adding seaweed to soil can re-convey those nutrients from where they are damaging marine ecosystems to the land where they can benefit depleted soils.

2.1 Seaweed Removal



Figure 5: *Manual harvest of Ulva from geoduck tubes in Washington (photo credit: Sarah Collier)*

Legal Harvest

It should be noted that state agencies want to ensure that the commercial harvest of wild-set seaweed from shellfish farms is approved and ecologically safe. Farms must list the fouling seaweed species they want to harvest on their Aquatic Farm Registration (AFR) (Appendix A). Harvest of fouling seaweed has to be from registered Aquatic Farm sites and the seaweed has to be attached to farm gear[33, 34, 35]. You can harvest seaweed recreationally from open shorelines if you have a current Washington state shellfish license and follow all applicable harvesting regulations (Appendix A).

Key Takeaways

Manual

- Manual removal requires no upfront cost and can be easily done without risk of damaging gear.
- Manual removal is difficult, takes a long time (~135 wet lbs/hr), and interferes with other farm operation needs as it occurs at low tide.
- The labor numbers and time to remove substantial *Ulva* manually could be high.

Mechanical

- Using a mechanical pump system to harvest *Ulva* can increase the harvest rate by 3.5x.
- This type of system decreases sediment on *Ulva* which eases processing and improves final products.
- This system operates during rising or falling tides, interfering less with other farm operations.
- This system requires a larger upfront and operational costs.

(a) Manual Removal

The simplest way to remove fouling *Ulva* from shellfish farm gear is by hand (Figure 5). Harvesters can use their hands or hand tools to remove *Ulva* from farm gear or the cultivated area at low tide. The benefits of this method is that it involves little to no investment in new equipment, and little training. The downsides to this method is that it removes laborers from normal farm activities and the extra pay associated with either increased labor hours or hiring more harvesters can increase farm costs quickly. The other large drawback of manually harvesting is that at low tide *Ulva* will lay flat on the tideflats. When you pick it up it will still have sediment on its blade. Unless the *Ulva* is washed well that sediment will be incorporated into any product the *Ulva* is used for. This can also increase the average weight of the seaweed that will be transported even after it is dried.



Figure 6: *11-gal plastic slotted fish basket used for Ulva harvest (photo credit: Hannah Garfield)*

An effective method for manual harvest is to use hands or pitch forks to remove the *Ulva* directly from shellfish farm gear at low tide and placing it in 11-gal (~1.5 ft^3) plastic slotted fish baskets (Figure 6). The slotted plastic baskets allow for water that was on the surface and inside of the *Ulva* to flow out of the basket. Dewatering is increased by stacking full baskets on top of one another which pressed more water out of the lower baskets. The water content of the baskets and *Ulva* does decrease rapidly, making the baskets lighter the longer they had time to drain. Once the baskets are full they weigh around 41 lbs (Table 2), so care should be taken when lifting solo or team lifting should be used. During low tides, using hands seems to be the best method to remove *Ulva* on geoduck tubes and oyster flip-bags suspended on lines, since pitch forks can damage the tubes and bags and there often is not enough space between the rows of tubes to scoop *Ulva* lying in between. If you are using hand tools, large squeegees seem to be useful during low tide in scraping *Ulva* off of flat sediment in preparation for seeding clams in intertidal mud and rakes also seem to be effective when removing *Ulva* off flat gear like predator exclusion nets (Chuckanut Shellfish, pers. comm., 2025). Pitch forks do seem to work when the tide flats are somewhat inundated, and harvesters can scoop *Ulva* that is slightly floating and load into baskets that are set on a floating barge (Calm Cove Shellfish, pers. comm., 2025). Long poles are useful on the filamentous *Ulva* when the tideflats are slightly inundated where they can then be used to sweep up the strands of *Ulva* suspended in between gear (Chuckanut Shellfish, pers. comm., 2025). If a barge is being used, as the tide comes in it can be floated to shore and full baskets can be carried from the high tide line to a ground transport (Calm Cove Shellfish, pers. comm., 2025) (Figure 7). If all the harvesting is done before the tide returns, the baskets full of wet *Ulva* can be transported by hand or by an ATV with a trailer to shore where they can be transferred for further transport (Figure 7).

Table 2: *Example of manual vs. mechanical harvest for Ulva (quantities, labor, rates)*

Baywater Shellfish Farm 2025	
Average weight of basket full of wet *Ulva*	41.3 lbs
Average volume of basket full of wet *Ulva*	11 gal
Ratio of *Ulva* wet weight to dry weight	6.2 - 7.9
Harvest Rate by hand	135 lbs/ hr
Harvest Rate by pump	480 lbs/ hr
Harvest Rate increase by using pump	3.5x



Figure 7: (*Left) Diagram of barge used to transport full Ulva baskets while collection occurred when tideflats were slightly inundated (diagram: Calm Cove Shellfish, pers. comm., 2025). (Right) ATV with trailer transported containers of Ulva from harvest area to the shoreline (photo credit: Sarah Collier).*

(b) Mechanical Removal

i.) Floating Pump and Venturi Suction System

A promising mechanical method is the 23hp Vanguard Engine & Pump with Electric Start pump system from Keene Engineering in Chatsworth, CA, USA (Table 4). The pump, engine, dewatering table, and battery are placed on a barge that can be moved manually or with an outboard motor over the shellfish farm area at higher tides. This pump system was originally designed for placer gold mining in rivers, but with a few modifications can be used to harvest nuisance *Ulva*. The major modifications are on the backend of the pump where a grated dewatering table is placed under the pump's outflow. The P350S pump (Table 4) can move 650 gallons of water per minute and is capable of 200’ of head lift. The pump, engine, hoses and collection table are attached to a barge where the hoses can be deployed into the water. For the hoses, there is a 3” diameter hose between the pump and the Venturi, a 4” diameter hose acting as the intake suction hose and a 5” hose is used for the discharge that empties onto the dewatering table (Chuckanut Farm, pers. comm., 2025). The size and shape of the barge can be made to fit the needs of the individual farm. A similar system is being used in Maunalua Bay, Hawai’i where SCUBA divers direct the intake hose underwater and feed invasive macroalgae into it as a removal method in the aims of improving coral reef health[36]. Right now, the use of

these pumps seems to be beneficial to farms, but a cost benefit analysis could validate their use economically. Overall, penciling out the economic losses caused by green tides on shellfish farms versus the cost of removal will be a great help in directing the creation and pricing of future products made from *Ulva* harvested from these farms and the methods used for *Ulva* harvesting.

ii.) How to Use

Once in place the pump is primed by placing the intake hose where the Venturi is located into the water and filling it with as much water as possible and holding the middle of the hose aloft so the column of water is in contact with the pump. The engine on the pump is started with an electric switch and once the suction is achieved and the flow rate is consistent the middle of the hose can be lowered. At least one crewmember is in the water with the intake suction hose and directs it over gear covered with *Ulva* (Figure 8). Some crew use a snorkel mask to better see the gear and *Ulva* under water (Baywater, pers. comms., 2025). The suction from the pump removes the *Ulva, runs* it through a discharge hose and deposits it onto a grated dewatering table. Here, the water from the intake falls through the grate below the table and through a hose back into the bay. Crew on the barge use their hands or scrapers to move the *Ulva* into the plastic baskets or larger vented receptacles (Figure 8). Here, the crew can also remove any rocks, bycatch, or debris. After preliminary trials we saw that this process decreases harvest time by at least 3.5x (Table 2). It can most likely become more efficient as crews get better at using the system and can steadily remove full containers of *Ulva* from the barge and replenish empty containers.

Table 3: *Mechanical vs. Manual Harvest*

Mechanical Harvest	**Manual Harvest**
Faster harvest rate ~(3.5x)	Slower harvest rate
Less sediment on *Ulva*	More sediment on *Ulva*
Fewer labor hours	More labor hours or more laborers
Can use at higher tides not interfering with normal farm operations	Occurs at lower tides which may interfere with normal farm operations
Expensive up front cost	Only requires more labor costs
Requires extra training for crew	Little to no extra training
Requires running engine while operating	Engine used not required
More fuel and maintenance costs	Less fuel and maintenance costs

Table 4: ***Prices of sample pump system parts***
Since exact length of hoses and needed connections will depend on the barge set up and some modifications will need to be made with the manufacturer to make it useful for seaweed harvesting the total price will differ. For reference one farm's total cost for the complete pump system in 2023 (excluding the barge) was ***$13,218.71*** *(Chuckanut Shellfish, pers. comm., 2025)*

Part	Price	Photo
23hp Vanguard Engine & Pump with Electric Start	$3,795	
Extended 4" Foot Valve Assembly	$365	
4" Power Jet with 3" Jet log	$493.90	
3" Heavy Duty Pressure Hose	$13.26/ ft	
4" Clearflow Suction Hose	$17.99/ ft	
5" Clearflow Suction Hose	$28.67/ ft	

4” Swivel Suction Hose Tip	$211.95	
Tachometer	$54.95	
Dewatering Table	$2,995.00	



Intake hose to prime pump and start Venturi effect



Intake hose where *Ulva* is suctioned up



Figure 8: *Images of 2 different floating pump and venturi suction systems at work harvesting Ulva from shellfish gear with important parts labeled (photo credits from top to bottom: Bill Dewey, Emily Buckner, Erick Dowell).*

2.2 Stabilization and Processing



Figure 9: *(Left) Wet Ulva just placed on racks inside the hoop house. (Right) Ulva after it has dried on racks in hoop house (photo credit: Erick Dowell)*

Key Takeaways

- To prevent decomposition and spoilage seaweed needs to be stabilized.
- Common stabilization techniques for seaweed are drying and fermentation.

Once seaweed is removed from the marine environment it will start to decompose. This includes intertidal macroalgae that can survive intermittent desiccation. While there are uses for fresh *Ulva* (such as a compost feedstock), if it is not used quickly it needs to be stabilized so it can be stored for long periods and more easily transported. A stabilization method needs to prevent the growth of microbes that cause spoilage and will make the *Ulva* unusable.The two methods we explored here are drying and fermentation. Drying stabilizes the seaweed by decreasing the moisture content to a low enough level that microbial growth is prevented (Figure 9). If the *Ulva* is unrinsed there is the added benefit of evaporating seawater leaving salt behind which will also help prevent spoilage. Fermentation stabilizes the product by rapidly decreasing the pH. The creation of a highly acidic environment promotes the growth of favored microbes which digest the seaweed into desirable compounds and prevents the growth of spoilage-causing microorganisms which cannot survive in a low pH environment. No matter which method is used, removing as much water as possible will result in quicker and better stabilization results.

2.3 Dewatering



Figure 10: *Stacking the baskets of seaweed makes it easier to transport while also increasing the rates at which water is lost. Any extra pressure added will force more water out (photo credits: Joth Davis, Emily Buckner)*

Key Takeaways

- Fresh *Ulva* is mostly water (~76-96%)[37].
- *Ulva* will naturally lose water once removed from the marine environment (>50% within 24 hrs).
- Dewatering reduces weight, eases transport and reduces transport costs.
- Mechanical dewatering methods can remove water more effectively, decrease drying time, and increase success in stabilization thereby increasing shelf life.

Ulva is mostly made of water (76-96%)[37] and water is heavy (1 gal = 8.345 lbs). *Ulva* will naturally lose around ⅓ - ½ of its water within a few hours once it is removed from the marine environment (PSRF, pers comm., 2025) so encouraging the dewatering process even more reduces the seaweed's weight and makes it physically easier to transport. You can passively dewater *Ulva* once it is in harvest baskets that are slotted and allow water to drain out as soon as the seaweed is removed from the water. Stacking baskets atop one another also encourages additional dewatering as the weight of the top baskets presses more water out of the *Ulva* in the baskets below (Figure 10).

More active dewatering systems could include a screw press which presses liquid out through constant pressure applied by a rotating and extending a screw on seaweed. Researchers at Idaho National Lab used a screw press to remove moisture (reducing moisture content by ~10%) (Bradley Wahlen, Idaho National Labs, pers. comm., 2025) and examined its effect on ensilage (a method of stabilization that uses fermentation). Their results showed that dewatering with a screw press does increase successful results when ensiling *Ulva* (Bradley Wahlen, Idaho National Labs, pers. comm., 2025). While there are screw presses in appreciable sizes for use at a shellfish farm, these are an extra expense in capital and energy, but could reduce overall drying time and increase success in later fermentation steps. There may be other mechanical options akin to a turf roller if the *Ulva* could be arranged on a flat surface or a mangler if *Ulva* could be continuously fed through. If the next step is drying, it should be noted that when *Ulva* is compressed it ‘sticks’ together very well which slows down drying as the outside layers will dry quickly but the inner, compressed layers will take longer to dry. There might be a point at which the decrease in water content reduces *Ulva*’s ability to stick together and prevent inner portions from drying out, but at this point that amount is unknown.

2.4 Drying



Figure 11: *Two 40' x 10' Hydrobuilder Heavy Duty Hoop Houses. We chose these since we were operating on an asphalt pad and they required no anchoring into the ground, and they were relatively easy to assemble and disassemble which was necessary since we leased the drying site and had to leave after the season (photo credit: Erick Dowell).*

Key Takeaways

- Drying stabilizes seaweed by removing water, preventing microbial growth.
- The goal is to reach <15 % moisture content.
- Using green houses protects *Ulva* from precipitation and passively increases drying temperatures.
- *Ulva* needs to be dried in a thin layer and flipped to ensure drying throughout.
- Increased temperature is important to decrease drying time, but air flow is as or more important in order to remove humid air away from the drying seaweed.
- Drying at higher temperature can decrease time and reduce moisture content, but this may cause losses in nutritional content.
- There are mechanical drying options that are used for the kelp industry and large scale dryers used for drying other crops that can be used to dry *Ulva*.
- Mechanical drying has a high upfront cost and high energy usage.

Table 5: *Seaweed Drying Data*

Optimal Temp. for passively drying seaweed[38]	140°F (60°C)
Optimal Relative Humidity for passively drying seaweed[38]	10%
Average Hoop House Temperature	75°F (23.9°C)
Hoop House Temperature Range (May - Sept.)	46°F(7.8°C) - 135°F (57°C)
Average Temp. difference between hoop house and outside	Δ14°F (7.8°C)
Largest Temp. difference between hoop house and outside	Δ75°F (41.7°C)
Average Hoop House Relative Humidity	55%
Hoop House RH Range	13% - 100%

(a) Passive Drying

Passive drying of seaweed has been used globally for millenia to increase the shelf-life of harvested seaweed. If there is space on the shore next to the shellfish farm, you can lay *Ulva* out to dry during the day. If you place the wet *Ulva* as thin of a layer as you can (the thinner the layer the faster it will completely dry) on elevated wire mesh racks (Figure 9), this will increase air flow, allow excess water to fall on the ground and decrease drying times. This has the added benefit of preventing sediment and debris from collecting on the *Ulva* and allowing some sediment attached to the *Ulva* to fall off as it dries. This method works well with the long summer daylight hours in the Pacific Northwest, but drying time is greatly increased if there is a precipitation event or heavy fog at night which will cause the *Ulva* to reabsorb the moisture and dry slower, especially in the mild air temperatures commonly seen in the temperate PNW maritime climate. To decrease the drying time but still dry passively you can place the *Ulva* in a greenhouse (Figure 11) so it is protected from precipitation and temperatures can increase above the ambient air temperature (Table 5). The type of greenhouse does not matter, but it should correspond to the area you have.

Drying in the hoop houses decreases the needed drying time when compared to drying outside, especially if there are precipitation events. Drying time decreases even more if the *Ulva* is placed on elevated wire mesh racks in hoop houses to increase air flow (Figure 9). The *Ulva* decreases in weight by over 50% within 24 hrs once it is placed in a hoop house. Usually within 3-5 days the seaweed will be 12 - 20% of its original weight. Changes in seaweed weight was used as a proxy for the remaining moisture content since fresh seaweed is usually 75-96% water[37] and fresh *Ulva* moisture content from Baywater has been seen between 58 - 90%[39]. The final dried *Ulva* weights were 12-20% of the original wet weight and these are close to the desired moisture content range of 10-15% for longer term stabilization[40].

(b) Active Drying

If more importance is put on increasing the volume of seaweed that can be dried in a given time period over reducing energy consumption and costs there are many commercial dryers available that have been tested on kelp species (but not *Ulva* to our knowledge). Since farmers are wanting to remove large amounts of *Ulva*, a continuous drying system, like a conveyor belt dryer would be appropriate[40]. These are suitable for bulk drying, have the ability to scale up, and produce dry flakes[40]. Since this is a common technology in the food industry there are many options available on the market. The downsides are that it is a large upfront investment and energy usage can be high. A heat exchanger could also be installed to conserve energy by utilizing waste heat in the drying process. Some models that are available are the Alvan Blanch CD222000 model which can dry 3,700 lbs/hr or the Scolari 2T244 model which can dry 6,800 lbs/hr[40]. Whether mechanical drying is used, passive solar drying can still be used to "pre-dry" *Ulva* before placing it into a dryer. This would decrease drying time in the dryer and energy costs.

(c) Challenges

Optimal passive drying conditions from Fudholi et al., 2011 are shared above (Table 5) with conditions experienced in the hoop houses. High temperatures and low relative humidities (RH) in the hoop houses during the day were close to optimal but at night temperatures approached ambient and the RH was often between 90-100%. This at least stops the drying process at night and at most rehydrates the seaweed, slowing down the drying process. To improve high temperature retention during nighttime, insulated greenhouses or thermal masses can be used, both of which would increase the cost, but there may be more affordable DIY options available.

Airflow is just as important as temperature when passively drying. RH reaches 90-100% most nights from trapped moisture in the hoop houses. Comparing drying rates of *Ulva* outside on racks, *Ulva* inside the hoop house on racks, and *Ulva* inside the hoop house on bed sheets show that air flow is important (Figure 12). When there was no precipitation, the drying times for *Ulva* on racks inside and outside were almost identical, and the *Ulva* not on racks with the least airflow dried the slowest. Wider openings in the hoop houses or solar-powered fans with batteries to allow for air flow to increase air flow could passively decrease RH more to improve drying.

Drying efforts are also hampered by *Ulva*'s ability to 'clump' together. The slight compression of *Ulva* in clumps slows the drying process. The outer layer dries while the inner layer remains moist even when elevated on racks. To counteract you will need to break apart and turn larger masses of *Ulva* every so often to ensure that the inside layers dry rapidly enough to prevent spoilage.

A final consideration is that high temperatures cause nutrient loss[40]. Aiming for temperatures between 95°F - 104°F (35°C - 40°C) and avoiding temperatures over 120°F - 150°F (48.9°C - 65.6°C) can help prevent nutritional degradation[40] and retain desired compounds[41] (Table 5). Locally there are nutritional differences seen between *Ulva* dried at 122°F (50°C) and at 212°F (100°C)[39]. More tests are needed to find which temperatures *Ulva*'s nutritional content starts to degrade. In addition, if *Ulva* is being dried for soil amendment, food

safety is not a concern, but if it is to be used as a human or animal food, then it will have to be exposed to higher temperatures to eliminate microbes for food safety.

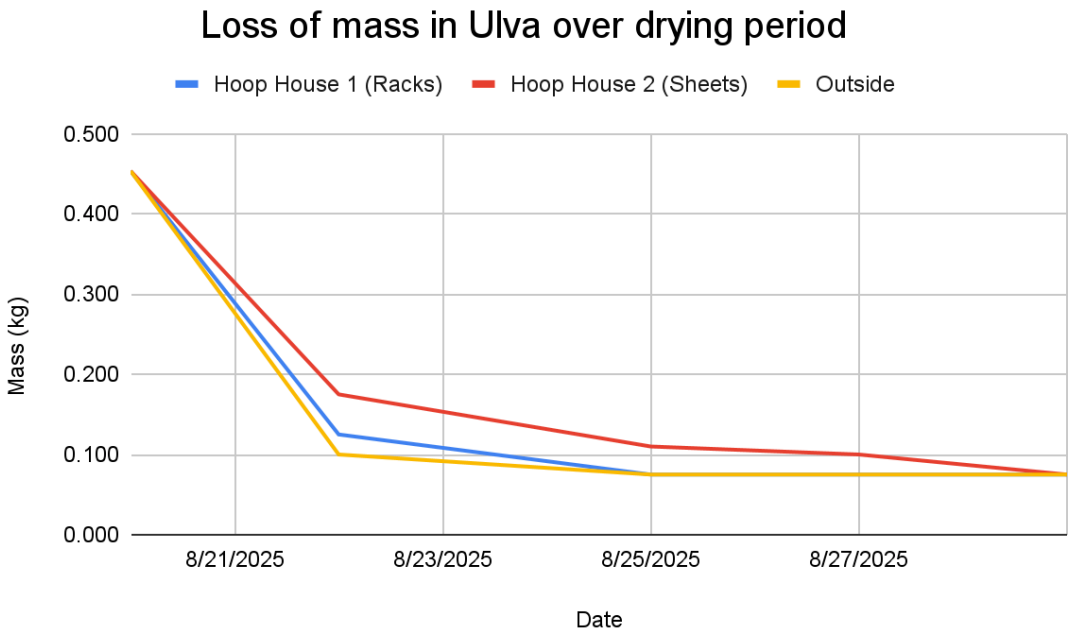


Figure 12: *Comparison of loss of water through a drying period of three fresh Ulva samples of equal starting mass. Seaweed on racks both inside and outside lose moisture at similar rates while seaweed with less air flow on the floor of the hoop house loses moisture more slowly.*

2.5 Mulching & Pelletizing



Figure 13: *Sample of dried Ulva (photo credit: Erick Dowell)*

Key Takeaways

- *Ulva* dries into non-uniform ‘chunks’.
- Mulching/ grinding can create uniformly sized dried product easing storage and use by terrestrial farmers or other end users

Even if spread in a thin layer, *Ulva* will dry in large, non-uniform chunks, ranging from golfball to dinner plate size (Figure 13). Complete further processing before storing or distributing to potential users so that it can be more easily stored, measured, distributed, and used by terrestrial farmers. A uniform size eases following rate application suggestion on fields and facilitates its mechanical spread with farm equipment, decreasing time and labor for terrestrial farmers.

Mulching the dried *Ulva* reduces and equalizes the average sizes of the pieces of *Ulva*. Using electric or gas-powered mulchers will quickly process the larger chunks of dried *Ulva* into homogenized smaller flakes (Figure 14). An electric leaf mulcher is economical, reduces the size but takes a long time, can only handle small volumes, and produces a lot of non-retrievable *Ulva* dust (Figure 15). A gas-powered wood chipper quickly reduces the size, creates uniform sized flakes, can handle larger volumes, and produces less dust waste (Margaret Homerding, Nisqually Indian Tribe, pers. comm., 2025) (Figure 15). A gas-powered push lawnmower on a flat hard surface can reduce the size of larger volumes of dried *Ulva*, but also creates a lot of dust and requires spreading the *Ulva* in a thin layer on a hard surface (Figure 15). For all mulching methods, there is some dust produced so proper PPE should be worn to prevent inhalation.

Another way to make a uniformly sized dried product and ease the use of *Ulva* by farmers and other users, could be pelletizing *Ulva*. Using a pellet mill would create a uniformly-sized pellet product that could easily be spread on a field by terrestrial farmers or used in animal feed (Figure 15). It would make storage simpler and cheaper since you could fit more *Ulva* into containers, and measuring the average nutrient content in one standard-sized *Ulva* pellet would be very useful to potential end-users. Other partners have also wanted to use a pelletized form of dried *Ulva*, proposing that it would yield better results in their use of *Ulva* as a biochar or biofuel feedstock.



Figure 14: *(Left) Ulva that has not been mulched. (Right) Ulva that has been mulched with Mighty Mac 12PT1100 Gas powered wood chipper (photo credit: Erick Dowell)*



Figure 15: *Fairly effective Ulva processing machinery - A) WORX 13A Electric Leaf Mulcher ($149), B) Mighty Mac 12PT1100 Gas powered wood chipper ($2,499), C) TechTongada 220V electric Pellet Mill ($1,300)*

2.6 Fermentation



Figure 16: *Adding salt to rinsed Ulva in preparation to ferment (photo credit: Emily Buckner)*

Key Takeaways

- Fermentation stabilizes seaweed by reducing pH dramatically thus disfavoring microbes that cause spoilage and favoring beneficial microbes.
- All types of fermentation involve metabolizing the product (usually by microbes). This will change nutritional content in positive or negative ways depending on the potential uses.
- Fermentation can be used as a preservation step that eliminates the needs for a drying step.
- A fermented product will have higher water content and weigh more than a dried one.
- Fermenting *Ulva* could produce a nutritional profile that is good for animal feed.
- Fermentation has been successfully used on many types of seaweed.
- Doing a pressing step prior to fermentation will positively impact results.

Fermentation is a type of anaerobic metabolism performed by microbes and has been used by humans for millennia to preserve humans and animal food including seaweeds. The goal of this fermentation is to increase the shelf life of the product by favoring beneficial microbes and disfavoring microbes that cause spoilage as well as create a useful product and byproducts. While fermentation takes time it does skip the drying process and can use *Ulva* when it still has a fairly high moisture content.

To perform a lactic acid fermentation follow the SOP below:

Day 1: *Collection*

- Collect *Ulva* in container that allows it to drain
    - Rinse if needed to remove sand and sediment
- Drain for ~ 1 day

Day 2: *Salting*

- Salt blades of *Ulva* with NaCl (Figure 16)
- Try to get even, heavy coverage on all the *Ulva* blades
- Attempt to get around ~10% salt
- Allow to drain for around another day

Day 3: *Fermentation*

- Fill water tight container with black plastic trash bag
- Fill bags with salted *Ulva*
- Use shop vacuum to remove much of the air out of the bags with *Ulva* and then tie shut and place lid on container
- We fermented for around 3 months*

Usage

- Has been shown to last for 3 years and still be good with kelp species
- Advise rinsing fermented seaweed before if using on soil or animal feed since it will still have a high salt content

*Fermentation times vary based on temperature, salinity, and the final use for the seaweed. A few months should be sufficient.

Sources:

Matt Hoehn (WDFW), pers. comm., 2025
Monteiro et al., 2021
Pinheiro et al., 2019
Reboleira et al., 2021

Another common fermentation technique used to preserve large amounts of biomass is ensilages where a material is preserved by tightly packing material to exclude as much oxygen as possible. The anaerobic metabolisms of certain microbes will digest the material while reducing the pH and sometimes microbes or acids are added to kickstart this process. Trials have shown that this is a possibility with *Ulva* and its success is enhanced by using a screw press to remove a lot of liquid prior to ensiling (Bradley Wahlen, Idaho National Lab, pers. comm., 2025). There is no salt added to this process, so it can be used without rinsing with fresh water.

3.0 How does your garden grow? *Ulva* as a Soil Amendment



Figure 17: *Ulva soil amendment trials on produce fields at Viva Farms (photo credits: Nicole Capizzi)*

3.1 Comparative Nutrients

Key Takeaways

- When compared to kelp meal, *Ulva* surpasses in N and P levels, but has lower K levels.
- *Ulva* is very high in iron, sulfur, magnesium, and calcium.
- *Ulva* surpasses kelp soil amendment in many secondary nutrients: Ca, Mg, S, Zn, Fe, Mn, and B.
- Nutrient composition of soil amendment *Ulva* can change throughout the growing season and processing.
- Since Organic Matter concentration (OM%) correlates significantly with almost all nutrients, it might be used to estimate nutrient content[39].
- Through multiple testing rounds, *Ulva* has shown safe levels of heavy metals.
- Local *Ulva* has usually shown heavy metal concentrations lower than commercially available soil amendments and regulatory thresholds.

- Dried *Ulva* has high sodium content.
- Rinsing *Ulva* with fresh water before use or applying in the rainy season is best practice to prevent damage to crops from sodium.

(a) Nitrogen - Phosphorus - Potassium (NPK)

In terms of macronutrients - nitrogen, potassium, and phosphorus - *Ulva* is low when compared to other organic soil amendments like seed meals, bone meals or compost[39] (Nicole Capizzi, pers. comm., 2025), but *Ulva* does outperform kelp soil amendments in nitrogen and phosphorus (Table 6, PSRF, pers. comm., 2025) and surpasses more common organic soil amendments in many important secondary nutrients[39] (Table 7, PSRF, pers. comm., 2025). Most of the potassium seen in *Ulva* disappeared after it was rinsed suggesting that it was in the sediment attached to it, but if the *Ulva* is used unrinsed this nutrient will still enter the soil. The structure of seaweed, like additions of any bulk organic matter, improves soil aeration and water infiltration. Its structure can also enhance plant growth by promoting nutrient uptake and utilization through retaining nutrients in the soil longer as it is broken down, nutrients are released and converted by soil microbes into forms usable by plants[39] (Tom Terry, pers. comm., 2025). The slow release of nutrients could reduce nutrient run when fields are rained on or irrigated, thereby decreasing the nutrient-rich agricultural run-off that eutrophies coastal waters and causes green tides[39].

Table 6: *Comparison of N-P-K values between Ulva and other organic soil amendments*

Soil Amendment	N	P	K
***Ulva* unrinsed 2024 Baywater homogenized (Capizzi, pers. comm., 2025)**	**1.32**	**0.22**	**0.85**
***Ulva* unrinsed spring, 2025 Baywater (Capizzi, pers. comm., 2025)**	**3.24**	**0.58**	**2.06**
***Ulva* unrinsed July, 2024 Henderson Inlet (PSRF)**	**3.24**	**0.46**	**1.56**
***Ulva* unrinsed August, 2025 Henderson Inlet (PSRF)**	**4.06**	**0.64**	**1.7**
Kelp meal	0.89	0.26	2.83
Fish Meal	10	6	2
Canola meal	6.6	6.41	1.44
Cottonseed meal	6.9	6.41	2.16
Soy Meal	6.5	1.5	2.4
Blood meal	12.5	1.5	0.6
Bone meal	3	20	0.5

(b) Secondary Nutrients and Micronutrients

Ulva as a soil amendment shows that local *Ulva* surpasses kelp meal in amounts of calcium, magnesium, sulfur, zinc, iron, manganese, and boron[39] (Table 7). It surpasses seed oils in calcium, sulfur, zinc, iron, and manganese. *Ulva* often has comparable levels of magnesium to other organic soil amendments and despite lower levels of macronutrients it still often has over half the levels of nitrogen found in compost and surpasses kelp meal's nitrogen amount. Its high levels of sulfur could make it a great additive for high pH soils[39] or for plants that prefer low pH soils (e.g. blueberries).

Table 7: *Comparison of nutrients in Ulva spp. from Washington and other organic soil amendments*

Source	PSRF	PSRF	Monis (2025)	Monis (2025)	Villares et al. (2013)	Fine et al. (2013)	Fine et al. (2013)
Sample	*Ulva* "lactuca"	*Ulva* "lactuca"	*Ulva* "lactuca"	*Ulva* "lactuca"	Kelp Meal	Cottonseed meal	Canola Meal
SITE	Puget Sound	Hood Canal	Hood Canal	Hood Canal	Spain	Oklahoma	Oklahoma
S (mg/kg)	27,600	21,150	22,600	18,900	7,400	5,000	8,000
B (mg/kg)	-	65	64.9	59.72	-	-	-
Ca (mg/kg)	16,500	7,750	8,950	8,280	6,900	2,000	7,000
Mg (mg/kg)	15,500	14,050	13,000	12,900	9,100	18,000	12,000
Zn (mg/kg)	34.2	254.8	114	21.3	63.5	65.7	68
Cu (mg/kg)	7.49	8.5	6.35	5.73	25.1	14.7	5.6
Fe (mg/kg)	7,490	6,643.9	7,260	7,700	211.7	90.1	78.3
Mn (mg/kg)	-	114.6	131	143	40.8	19.7	73.4

The current challenge of marketing *Ulva* as a soil amendment is providing accurate dry weight nutrient concentration information. Terrestrial farmers know their soils well, and know what they need for improved soil health. To show that *Ulva* soil amendments can be useful for them, the approximate average nutritional content of locally sourced, dried and processed *Ulva* needs to be calculated and advertised so that farmers can calculate how and how much *Ulva* will benefit their fields or replace their other amendments. There is variability seen in nutrient profiles of *Ulva* from different harvest areas, harvest times, rinsed vs. unrinsed, and drying temperatures. Any techniques or processes that standardize the nutritional profile or increase its reliability will make *Ulva* more of an appealing soil amendment and easier for terrestrial farmers to use.

In Monis 2025, the author explored using organic matter concentrations (OM%) as an estimate of nutrient content, since results showed that nutrient concentrations all correlated significantly with organic matter concentrations, except for calcium. The author also showed that OM% could be a proxy for total moisture loss in *Ulva*. These correlations could be used to help develop standardized processing methods for local *Ulva* harvested from shellfish farms. They

could be applied to processing methods that work best for shellfish farms, instead of dictating preferred processing methods since this market pathway, at least at first, will be shaped by the capacity and materials available to shellfish farmers[39].

(c) Heavy Metals

Table 8: *Heavy metal concentrations in Ulva based on the aggregation of the first four harvest dates, Washington State Department of Agriculture standards for agricultural application, and the corresponding allowable application rates in agricultural soils based on each heavy metal. (from Monis, 2025)*

Heavy Metal	WA State Standards for Metals (lbs/ac/yr)	Concentration in *Ulva* (mg/kg, beach-dried, as-is seaweed)	Allowable application rates for beach dried as-is *Ulva* (lbs/ac/yr)
Arsenic	0.297	4.00	74,258
Cadmium	0.470	0.346	228,339
Lead	1.98	0.00910	2,087,643
Mercury	0.0190	1.20	1,651,051

Another important piece of information that terrestrial farmers need to know about a potential new soil amendment is if it will affect their crops' value in any negative way. Plants absorb nutrients from the soil and can be very efficient at absorbing and concentrating metals that are toxic to humans as well.

So far, all results have shown *Ulva* to be a safe soil amendment when regarding heavy metal concentrations. *Ulva* has lower levels of cadmium, lead, and mercury when compared to other soil amendments (Table 8). Its arsenic levels are either comparable or lower than other commercial organic fertilizers. *Ulva* from different harvest locations show levels of heavy metals that are stable and safely below Washington state thresholds for soil amendments (Table 8, Appendix F). *Ulva* also shows arsenic, cadmium, and mercury levels lower than brown seaweeds commonly used for soil amendments, like kelps (Appendix F). When determining application rates arsenic is the limiting factor and the maximum application rate for *Ulva* in Washington would be 74,258 lbs/ac/yr[39].

While heavy metal concentrations found in *Ulva* harvested from shellfish farms have so far been low and under safe limits, the absorption of heavy metal by seaweed will often correspond and change with the relative concentrations of heavy metals in the surrounding water column where higher heavy metal concentrations are found in seaweeds growing in areas with higher concentrations of heavy metals in the water[48]. Heavy metal testing should continue if the use of wild harvested *Ulva* on shellfish farms becomes a common practice.

(d) Salt Content

Plants are sensitive to salt and since *Ulva* comes from a marine environment it will contain salt. Seaweeds do not have much salt inside their cells, but the seawater on their blades evaporates and leaves a layer of mostly sodium chloride (NaCl) behind.

The salt tolerance for most common crop plants is well known (Figure 18), and avoiding salt sensitive plants is an obvious choice to avoid negative impacts of using *Ulva* as a soil amendment. The dried *Ulva* can also be rinsed before being applied to the soils. Tests from around the globe have shown that the salt content drops (~90%) once *Ulva* is rinsed with freshwater [49, 50](Capizzi, unpublished results). Rinsed *Ulva* has shown negligible effects on the soil salinity: 0.029 ppt in plots with rinsed seaweed and 0.024 ppt in plots without seaweed (Tom Terry, pers. comm., 2025)(Appendix B).

But, freshwater access can be difficult especially at shellfish farms and can also be costly if you need to rinse large amounts of *Ulva*. To avoid this extra processing step and cost, farmers could apply the dried *Ulva* to fields in the late winter or early spring (for the western Washington area weather) in order to take advantage of the ample rains. An initial local study showed that the sodium content does not build up and does migrate down through the soil column (Capizzi, unpublished results). No large scale studies on multiple heavy applications of unrinsed *Ulva* on fields have been done though, so this may have to be tested more. Sodium residence times will also most likely increase in soils that have higher clay content and poorer drainage.

Another possible way to reduce sodium levels is through adding wet *Ulva* to a composting system with another dry, high carbon feedstock before adding it to fields as this will dilute the sodium levels, and letting the decomposition process happen uncovered will allow precipitation events to rinse much of the sodium away [51, 50].

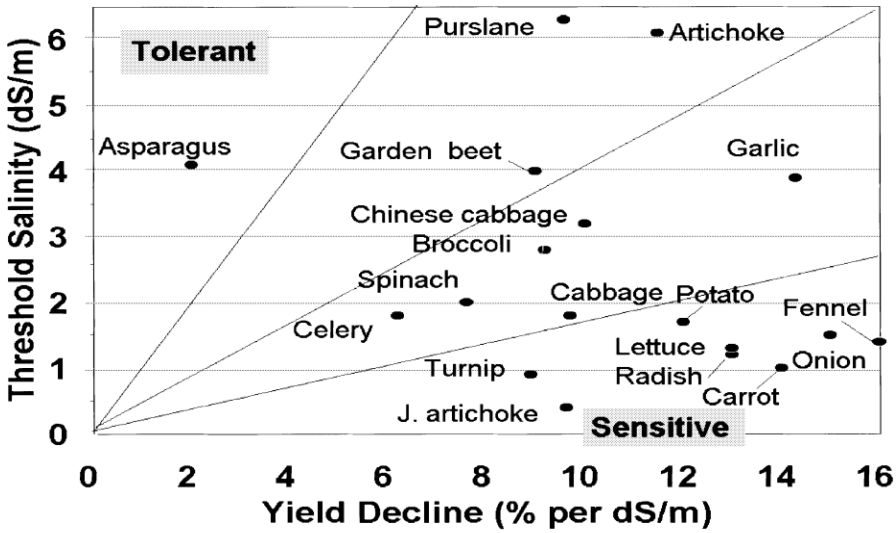


Figure 18: *Salt tolerance of several vegetable species as rated by the salinity threshold and percent yield decline*[52]

3.2 Garden Performance

Key Takeaways

- Dried *Ulva* soil amendments that have been rinsed have had positive effects on all crops tested so far.
- *Ulva* has significantly increased growth in kale, Swiss chard, shallot, garlic, onion, and cucumbers.
- Since *Ulva* does not have a high nitrogen content (N-P-K: 2.2-0.11-1.7), there was a benefit of the organic material of the *Ulva* acting as a slow release mechanism into the soil and the addition of the secondary nutrients found in *Ulva*
- Rinsed *Ulva* soil amendment caused negligible increases in soil salinity: 0.029 ppt in plots with seaweed and 0.024 ppt in plots without (Appendix B).
- Kale grown with *Ulva* shows Cd, Pb, and Hg levels below detectable limits and safe, and very low levels of As.



Figure 19: *Difference of kale leaves grown with Ulva soil amendment compared to those grown without (photo credit: Tom Terry)*



Figure 20: *Difference of Swiss chard grown with Ulva (red check marks) and those grown without (no markings) (photo credit: Tom Terry)*

Growing Swiss chard, kale, garlic, shallots, onion, and tomatoes with an *Ulva* soil amendment have all shown positive results (Figures 19, 20), all of which have been significant except tomatoes which had too few replications to calculate significance (Tom Terry, pers. comm., 2025)(Figure 21)(Appendix E). The results have been particularly successful for hearty greens like chard and kale (Tom Terry, pers. comm., 2025).

If trying out in the garden:

Step 1 - **Test *Ulva*:** For these garden trials the *Ulva* nutrient profile was NPK ~ 2.2-0.11-1.7 and heavy metal content was low and safe (Appendix C)(Appendix D)

Step 2 - **Test the soil:** Often conservation districts have soil testing services and will provide advice on how much amendment should be applied.

Step 3 - **Application rate:** With the help of a conservation district or other agricultural organization use the local soil test results and *Ulva* nutrient profile to determine the application rate. It is advised that *Ulva* be added between 0.25 - 0.57 lbs/ft^2. Adjust for moisture content and determine the amount of nutrient applied per area.

Example from Garden Trials (Tom Terry, pers. comm., 2025):
0.57 lbs. / square foot of air-dried seaweed applied
43,560 square ft / per acre
43,560 x 0.57 = 24,394 lbs. / acre of air- dried seaweed
Adjusted for 7.5% moisture content = 22,540 lbs. acre
N-P-K analysis of the applied seaweed = 2.2 - 0.11 - 1.7
22,540 lbs. x 0.022 = 496 lbs. N / acre
22,540 lbs. x 0.0011 = 25 lbs. P / acre
22,540 lbs. x 0.017 = 383 lbs. K / acre

Step 4 - **Determine nutrient release over time:** Since *Ulva* is an organic amendment it will need to decompose to release its nutrients slowly over a longer period of time to make them available to plants. Oregon State University has an Organic Fertilizer Calculator that can help determine when and what proportion of nutrients from your amendment will be plant available. Use this information to check if your application rate will provide the suggested nutrient amount over time in your soils.

Example from Garden Trials (Tom Terry, pers. comm., 2025):

~20% of the N in applied fresh organic material with a concentration of 2.2% (the N content of *Ulva*) will be plant available (Plant Available N [PAN]) over a 10-week period. At an application rate of 0.57 lbs. /ft^2 of dried *Ulva*
that amounts to 99.2 lbs. of N (496 lbs. N applied in the *Ulva* material x 0.20 = 99.2 lbs.), which is close to what the soil test recommended.

Step 5 - **Prepare and apply *Ulva*:** Dried *Ulva* can be pulverized or mulched into small flakes, then rinsed 2-3x in fresh water. You can also rinse freshly harvested *Ulva* before you dry. After rinsing it can then either be redried before application or applied wet. It can be applied on top of the soil or mixed in. After rinsing in freshwater or applying in late winter / early spring there was no increase in soil salinity (Tom Terry, pers. comm., 2025).

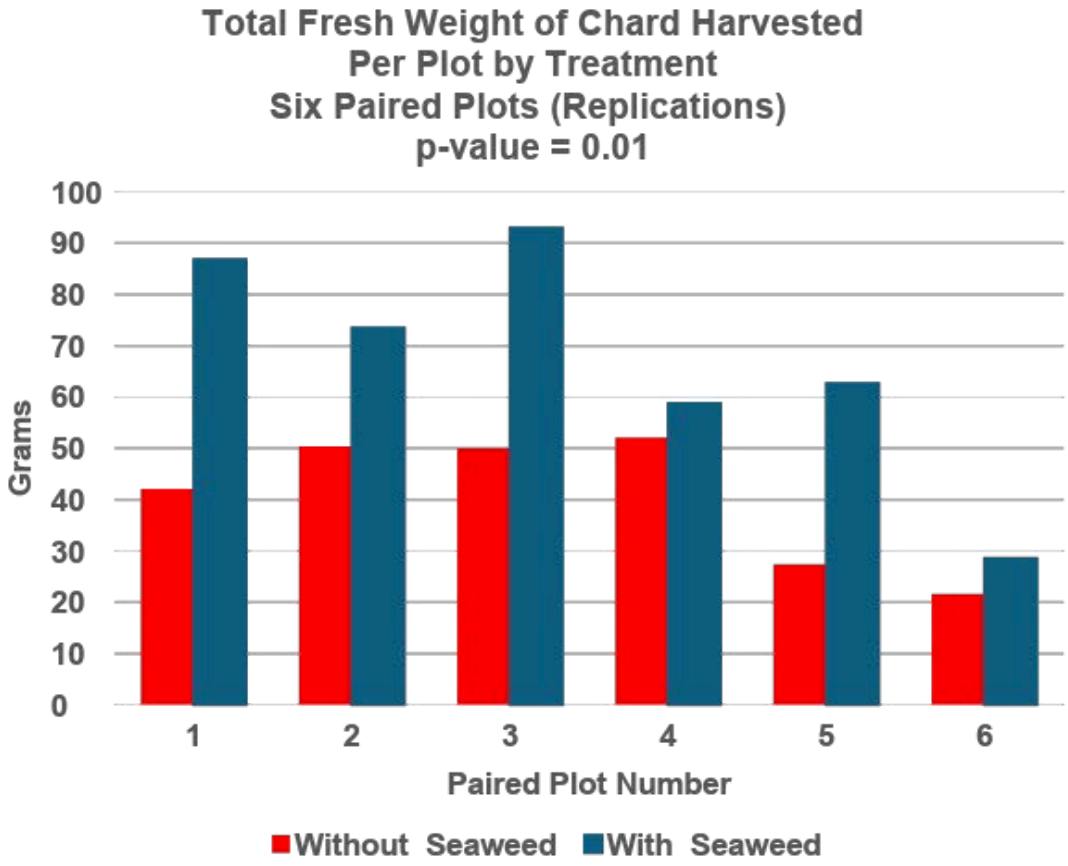


Figure 21: *Here you can see the increased growth in Swiss chard that had Ulva soil amendment (blue) added vs. the chard that did not (red) (figure and data from Tom Terry)*

3.3 Upland Connections



Figure 22: *Dried Ulva placed on produce fields to test impact on growth and addition of carbon to soil (Blue Carbon Green Fields project, photo credits: Sarah Collier)*

Key Takeaways

- There are a variety of market pathways to get *Ulva* into soils of upland users
- Creating a local community of users near shellfish farms can hopefully increase the sustainability of this practice, community resilience, and local knowledge of marine and terrestrial food systems and watershed impacts.

To facilitate the creation of a market pathway from sea to land that will be long-lasting and sustainable, creating partnerships and networks between shellfish farmers who have an abundance of nuisance *Ulva* and upland users who want to increase their soil health with locally produced, natural fertilizers is key to ensuring stability of this regenerative practice. These networks can take several forms, some connect shellfish farms with the broader community of gardeners in their watershed, whereas others connect shellfish farms with commercial for-profit terrestrial farms .

(a) Farm to Farm

Connecting shellfish farms to nearby terrestrial ones seems to be a large win-win method for a pathway for nuisance *Ulva* to benefit soils. This would decrease waste, convey nutrients from the eutrophied coastal ecosystems to nutrient depleted agricultural fields and hopefully decrease some of the agricultural runoff exacerbating local green tides. Many local terrestrial farms are interested in using organic and regenerative methods to improve their soil health especially if it benefits other local food producers and shortens farmers' supply chains.

Since terrestrial farmers are running a business with thin margins they will need proof of *Ulva*'s safety and effectiveness and any help from past users and researchers on on most effective practices for processing and applying *Ulva* will be helpful to reduce the cost of using the *Ulva*, encourage more farmers to use it and pinpoint an accurate price to what *Ulva* may eventually be sold for (Figure 17, 22). The Farm to Farm method is the simplest in terms of logistics and supply chains since it involves direct one on one communication. This method could scale up into something larger in complexity and capacity if one farm receives as much seaweed as possible and is able to be a distributor to more interested local farms.

Examples:
Wet *Ulva* from Calm Cove Shellfish Farm for compost used by Native Sun Cannabis Farms.
Dried *Ulva* from Baywater Shellfish going onto brassicas at the local Chimalow Produce farm
Wet *Ulva* from Baywater Shellfish for compost used by Chimacum Grainery.

(b) Farm to Community

Another network model is connecting a shellfish farm with local community members interested in the health of their local watershed where the shellfish farm is located. Some of these community members could be avid gardeners excited to trial using *Ulva* as a soil amendment in their personal garden. This method could be the start of a CSA (community supported agriculture) like model where community members would pay a membership to the shellfish farm to regularly collect harvested *Ulva* to use in their gardens. This method has been developing successfully between Nisqually Indian Tribes Shellfish Farm and the community surrounding Henderson Inlet (Figure 23). These users still need evidence that use of *Ulva* as a soil amendment is safe for their plants and them as well as some educational materials showing how to and how much to apply.



Figure 23: *Event at Meyer's Point celebrating and educating about Ulva removal, water quality improvement, and community involvement at Henderson Inlet (photo credit: Erick Dowell)*



Figure 24: *Members of a work party remove Ulva from oyster bag lines (photo credit: Emily Buckner)*

(c) Work Parties

Another model is work-party style where attendees would come and harvest *Ulva* from the shellfish farm in their community. Here they would learn about the causes of green tides, how they as upland neighbors affect the water quality, the impacts of green tides on shell fish farms, and its potential benefits as a soil amendment. They would also learn more about the operation of shellfish farms as well as more about their local food systems. They would leave the event with a lot more knowledge about shellfish farms, green tides, their watershed, and bags of *Ulva* that they could apply to their gardens. Similar to the CSA model this method focuses on connecting community members with the shellfish farm in their watershed. The hope is to encourage more events where *Ulva* can be removed, eventually popularizing its use and increasing demand for it. This method was piloted by WSU student Noelle Beecroft who created a community event around community *Ulva* removal from Drayton Harbor Shellfish Farm in Blaine, WA (Figure 24).

3.4 Innovative Connections

Key Takeaways

- *Ulva* can be used for more than a soil amendment and many researchers are studying different uses for it.
- All of these uses will most likely entail either more processing, more regulations or both.
- If the nascent west coast kelp farming industry invests in processing methods and equipment, *Ulva* may be able to piggy-back on these methods since kelp and *Ulva* have different growing and harvesting seasons.

Recently, more novel uses for seaweed have been investigated. Some examples include:

- Carbon sequestration through farming in high nutrient, low productivity ocean zones and processing into carbon sequestering products (like biochar) or replacements for fossil fuels - SeaO2[53]
- Carbon sequestration and building material by incorporating dried *Ulva* into cement as a replacement ingredient to reduce the emissions associated with cement production and store carbon inside *Ulva* that would have otherwise been released once the *Ulva* decomposed - Roumeli Lab at UW[54]
- Bioplastics from *Ulva* since it has a propensity to ‘stick’ together. With only the addition of pressure and some heat and hard bioplastic can be produced - Roumeli Lab at UW (pers. comm., 2025).
- Livestock feed for goats. *Ulva* is edible to humans and animals and has been tested as a feed before. It is approved for animal feed in WA and is recommended for ruminants and finfish - Chimacum Family Dairy[55].

- Biomining seems to be possible from *Ulva*. While it absorbs heavy metals in the water column around it it can also absorb more valuable metals from seawater and outperforms other local species of seaweeds by absorbing rare earth metals that are used in manufacturing electronics - Pacific Northwest National Labs (Tom Mumford, pers. comm., 2025)

Many of these uses may require the feedstock seaweed to have a reliable supply and nutrient composition, so it may not be suitable for wild-set nuisance *Ulva* harvested from shellfish gear, but some innovative uses may match up. Nuisance *Ulva* could also serve as a supplemental input to a larger supply chain. These products often need more processing steps, leading to higher costs if more equipment needs to be bought or an intermediary used. Synergies with the growing seaweed farming industry on the North American west coast may be possible here as those industry players are searching for appropriate processing methods and infrastructure to create desirable and value-added products to send to market. Once those processes are developed and infrastructure built or found, *Ulva* harvested from shellfish farms could use the same infrastructure to create non-competing products. Even if both sugar kelp (the most popular seaweed farmed on the west coast) and *Ulva* are both made into soil amendments, as seen above, they have different nutrient profiles preventing them from being competitors. The use of the same processing equipment that kelp farming utilized would be a great match since *Ulva* and sugar kelp's growing and harvesting seasons do not overlap much.

Potential Recurring Funding Sources

Table 9: *An inexhaustive list of some recurring funding sources that are applicable to this work.*

Funding Source	Description
Washington Dept. of Commerce Industrial Symbiosis Grant	Funds collaborative projects that divert waste streams generated by one industry into a beneficial resource for another.
USDA Sustainable Agriculture Research and Education	Several categories of these grants are applicable based on who one might partner with and they focus on improving sustainable agricultural practices
USDA Value-Added Producer Grant	Helps producers enter into value-added activities through supporting planning activities or capital needs.
National Institute of Food and Agriculture AFRI Foundational and Applied Science Program	The Bioeconomy and Biobased products program priority seeks to improve biomass systems especially if they support the circular economy
Climate Smart Communities Initiative	Provides funding to increase community-based resilience in US communities that are vulnerable to the impacts of climate change

Important Questions to Answer

- What is *Ulva*'s effectiveness as a soil amendment for a variety of crops?
- What is the safety regarding salinity and heavy metal impacts on soil over multiple applications?
- What are the most effective practices for processing and applying *Ulva* on agricultural fields to reduce the cost and ease use by farmers?
- What is an appropriate price for *Ulva* sold as a soil amendment (taking into account farmers' willingness to pay and shellfish farmers' cost to remove)?
- What is the average nutritional content of locally harvested *Ulva* (so it can be marketed more effectively)?
- What is the average heavy metal content of *Ulva* (so recommended application rates can remain below regulatory thresholds)?
- How much do green tides damage shellfish growing operations in labor costs, shellfish mortality, and decreased growth rates (so the economic benefit of removal can be calculated)?
- What are the costs and benefits of different processing and stabilizing methods for *Ulva*?
- Can other, local biomass processing facilities be used to process *Ulva* into soil amendments or other products?
- Can *Ulva* be incorporated with other seaweeds or waste streams to create even better and a wider variety of soil amendments?

Conclusion

Ulva that fouls shellfish aquaculture gear is both plentiful and harvestable. It also can be used successfully as a growth enhancing soil amendment. There are even others globally (i.e. in Zanzibar[56] and Indonesia[57]) who are harvesting, processing and selling wild *Ulva* currently indicating that perhaps there is a market beyond western Washington. Some lingering economic and ecological questions remain, though. While there are effective methods that can harvest and process the seaweed into a shelf-stable form, a large market and thus demand does not exist yet and the processing, storing, and transportation bottlenecks loom large in an area where space and labor are expensive. Developing more interest in potential *Ulva* users and honing in on the costs and benefits both economically and ecologically of seaweed removal from shellfish gear will provide a better roadmap for market pathways to turn nuisance *Ulva* into a desirable commodity.

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Appendices

Appendix A: Washington DNR Fact Seaweed Harvest Factsheet

WASHINGTON STATE DEPT OF NATURAL RESOURCES

Harvest of "Incidental Seaweed" from Aquaculture Leaseholds for Commercial Purposes

The Washington Department of Natural Resources (DNR) is tasked with facilitating water-dependent uses on state-owned aquatic lands, when consistent with other mandates, including environmental protection. Recently, DNR has seen an increased interest in the harvest and commercial use of seaweed. In this context, seaweed means saltwater marine plant species that are dependent upon the marine aquatic or tidal environment, and exist in either an attached or free-floating state. Marine aquatic plants include but are not limited to green algae, brown algae (including kelp), and red algae. Native kelp and other seaweeds provide important habitats that feed and provide shelter for salmon, forage fish, and numerous other species.

Seaweed Attached to Tenant-Owned Improvements

Because seaweed has inherent value and provides essential habitat, commercial harvest of seaweed, either attached (to substrate) or free-floating, is prohibited on all state-owned aquatic lands, as well as private tidelands (RCW 79.135.410). However, upon request, DNR *may* allow the commercial collection of naturally set seaweed from tenant-owned improvements, so long as these activities are *listed as permitted uses in a lease/sublease* (RCW 79.135.100), and provided that the seaweed is attached entirely on tenant-owned improvements within the leasehold. The lease should include any site-specific conditions needed to ensure environmental protection of state-owned aquatic lands. The site from which harvest is to occur must also be a registered Aquatic Farm with the Department of Fish and Wildlife (WDFW; RCW 77.115.010). Possession of commercial quantities of seaweed harvested from tenant-owned improvements is unlawful without a valid Aquatic Farm Registration (AFR) and a copy of the DNR lease or sublease specifically authorizing commercial collection as described above also in possession. Both a valid AFR and copy of the DNR lease/sublease must be available for inspection by WDFW and DNR Enforcement.



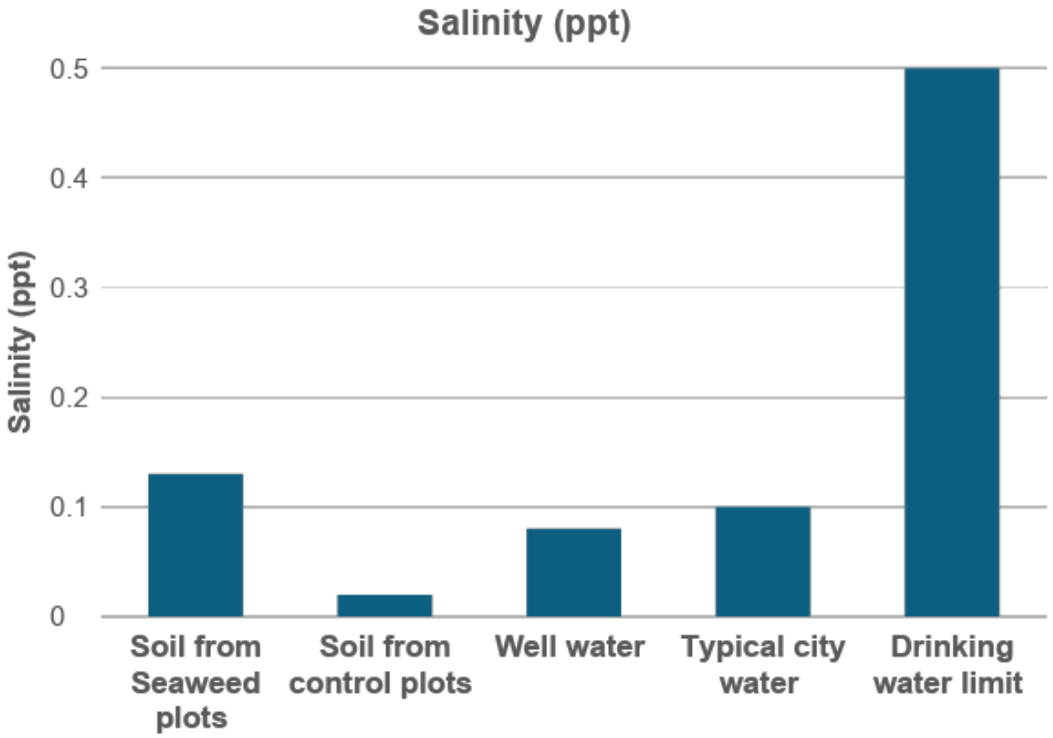
Free-Floating Seaweed

Seaweed that floats onto a site and gets caught up in tenant-owned improvements may not be commercially harvested. However, this "nuisance" seaweed may be removed from tenant-owned improvements, so long as it is left to decompose in place.

Seaweed Aquaculture

DNR may lease state-owned aquatic land for the purpose of seaweed aquaculture, or for integrated aquaculture involving seaweed production in tandem with other uses, such as shellfish aquaculture.

Appendix B: Soil and Water Salinity Comparisons



Appendix B: *Comparison of soil salinity with Ulva amendment to soil without Ulva amendment and concentrations in potable water sources and local drinking water salinity regulatory thresholds.*

Appendix C: *Ulva* Nutrient Data

Appendix C Table: *Nutrient Comparison of Ulva harvested from Henderson Inlet, WA from three different years with commercially available kelp meal. *Kelp Meal data from Villares et al., 2013*

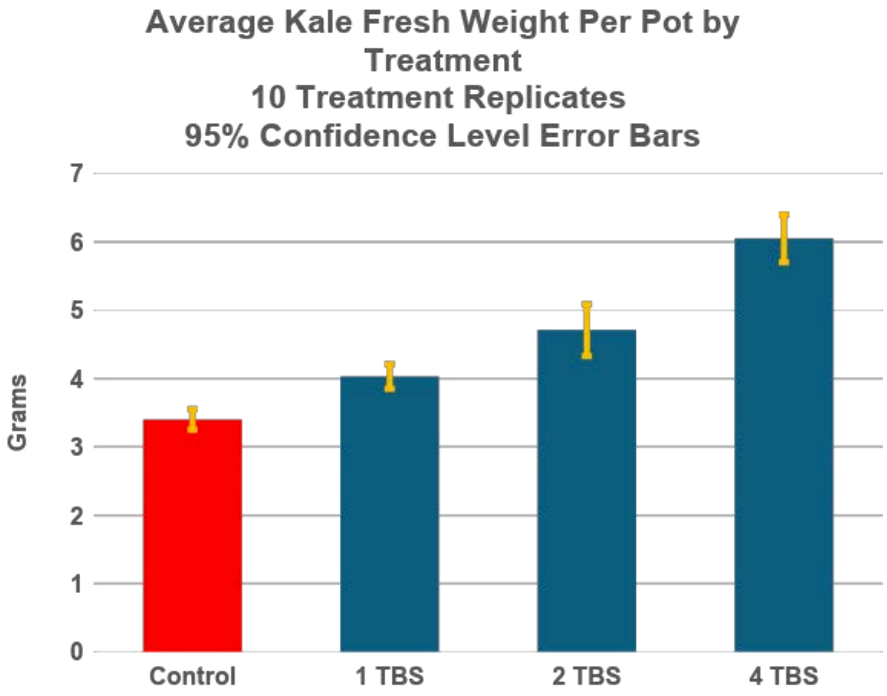
SAMPLE	TOTAL N (%)	NO3 (mg/kg)	P (mg/kg)	K (mg/kg)	S (mg/kg)	B (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Zn (mg/kg)
AUGUST 2025	**4.06**	125	**2,818**	14,186	**32,352**	**46.4**	7,113	13,138	117
JULY 2024	3.24	**367**	2,076	13,110	28,837	45.8	11,182	**15,902**	**150**
AUGUST 2023	–	–	1,130	**16,800**	27,600	–	**16,500**	15,500	34.2
KELP MEAL*	1.07	–	–	–	7,400	–	6,900	9,100	63.5

Appendix D: *Ulva* Heavy Metal Data

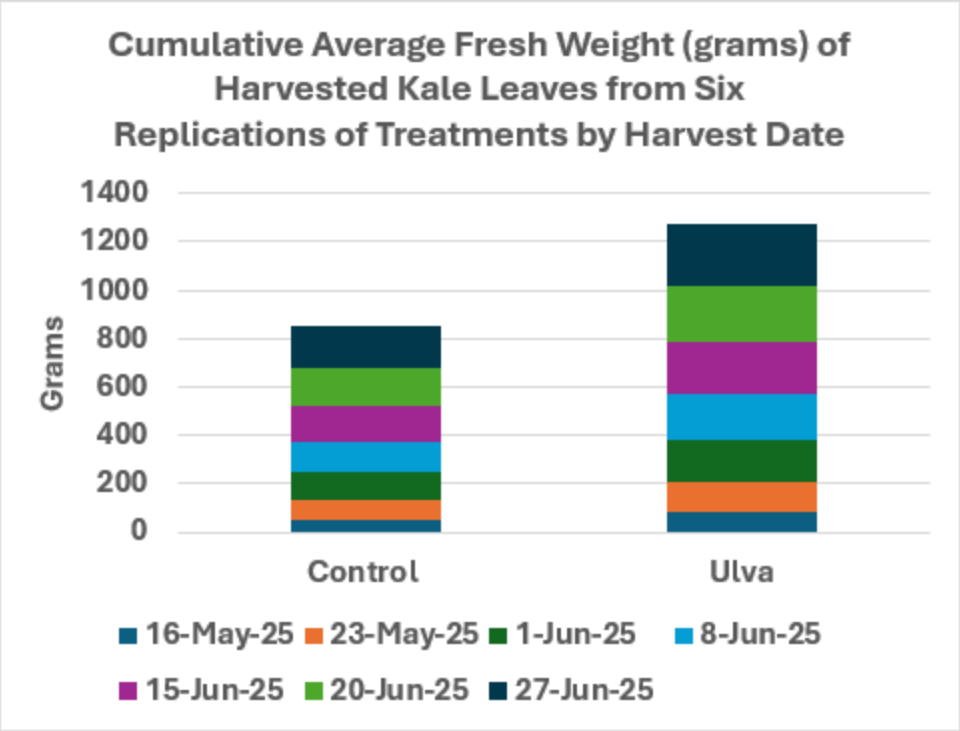
Appendix D Table: *Heavy Metals in Ulva harvested from Hood Canal, WA (Baywater) and South Puget Sound,WA (Henderson Inlet)*

Site	Year	As (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Hg (mg/kg)
Henderson GH Dried	2023	4.36	0.33	2.97	0.023
Baywater Beach Dried*	2024	4	0.346	1.2	0.0091
Henderson GH Dried	2024	0.06	0.1	<MDL	–
Henderson GH Dried	2025	1.76	0.04	<MDL	–
Baywater Rinsed, Beach Dried*	2024	5.42	0.556	<MDL	0.008
Baywater Rinsed, Oven-dried*	2024	6.46	0.363	<MDL	0.008

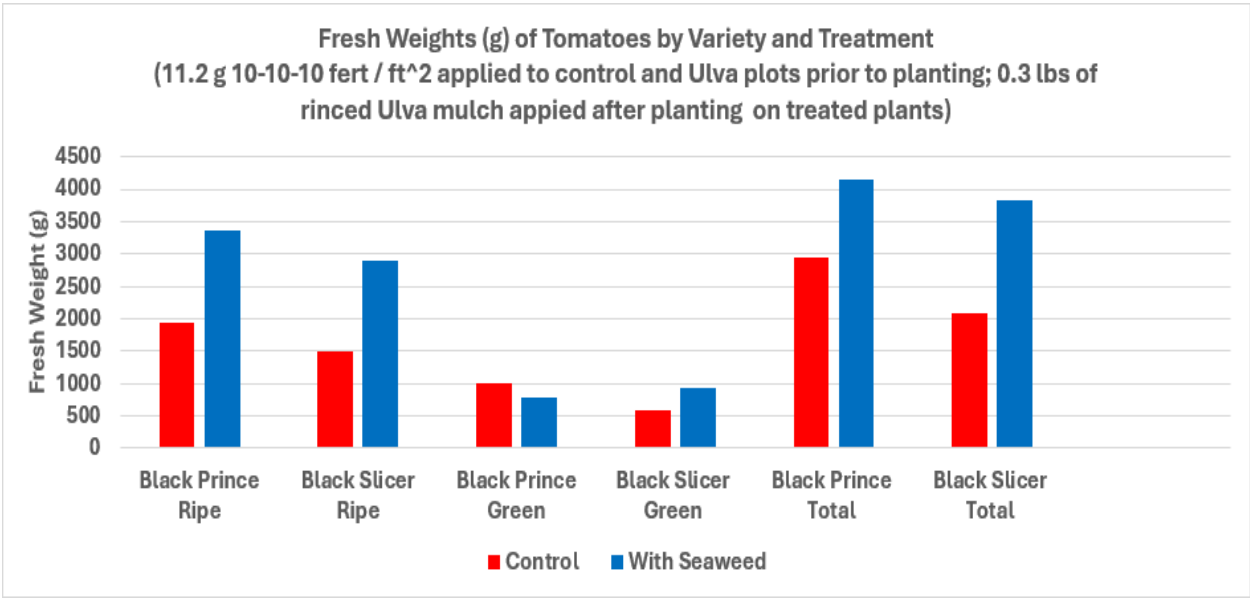
Appendix E: *Ulva*'s Impact on Plant Growth



Effect of increasing addition of Ulva soil amendment on kale (Prizm variety) growth. Ulva was rinsed and pulverized and added to a gallon of potting mix (⅓ peat moss, ⅓ vermiculite, ⅓ perlite, and tbsp of mycorrhizal inoculant). (p = 0.01) (figure and data from Tom Terry)



Comparison of cumulative kale leaf growth with Ulva soil amendment and without. The largest leaf was harvested from the two plants in each plot for each of the seven dates sampled. There was 49% more cumulative growth in the Ulva treated plots (figure and data from Tom Terry)



A Comparison of the growth of different varieties of tomatoes with an without the addition of an Ulva soil amendment

Appendix F: Heavy Metal Comparisons

Analytical Laboratory: Brooks Applied Labs
Seaweed Batch: BW24.1
Sample Type: Air-dried seaweed
Laboratory Sample ID: 2407233-01
Report Compiled By: UW BCGF MMRV (Monis, Collier, Johnson)

Seaweed Batch: BW24.test

		Percent % (DM*)	mg/kg (DM)	lbs/ton (DM*)	lbs/ton (as-is**)
Total Carbon	TC	21.2			
Total Nitrogen	TN	2.71		54.2	52.1
Phosphorus***	P***	0.14			
Potassium***	K***	1.98			
N-P-K equivalent*** 2.71-0.33-2.38					
Sulfur	S	2.12			
Calcium	Ca	0.77			
Magnesium	Mg	1.41			
Sodium	Na	2.53			
Zinc	Zn		254.8	0.51	0.49
Manganese	Mn		114.6	0.23	0.22
Copper	Cu		8.5	0.02	0.02
Iron	Fe		6643.9	13.29	12.78
Boron	B		64.9	0.13	0.12
Ammonium (available nitrogen)	NH4-N			0.25	0.243
Nitrate (available nitrogen)	NO3			0.71	0.682
pH (1:5)	pH 5.7				
E.C. (1:5)	E.C. 18.74				
Carbon : Nitrogen ratio	C:N 7.8				

Canola meal for comparison (Bary, 2016)

	Percent% (DM*)	lbs/ton (as-is**
TN	5	
P2O5***	1	
K2O***	1	

Dried Poultry manure for comparison (Bary,2016)

	Percent% (DM*)	lbs/ton (as-is**
TN	4	
P2O5***	3	
K2O***	3	
N-P-K equivalent*** 4-3-3		

Yard debris compost for comparison (Bary, 2016)

	Percent % (DM*)	lbs/ton (as-is**)
TN	1.7	18
P***		3
K***		8
C:N 17		

***Organic amendment analyses are usually reported as P and K, while fertilizer labels use P2O5 and K2O. To convert from P to P2O, multiply by 2.3. To convert from K to K2O, multiply by 1.2. 1. Bary, Andy & Cogger, C.G. & Sullivan, Dan. (2016). Fertilizing with Manure and Other Organic Amendments. Oregon State University Extension Publication PNW533. Oregon State University.

BCGF Seaweed Metals Analysis 2024

Analytical Laboratory: Brooks Applied Labs
Seaweed Batch: BW24.1
Sample Type: Air-dried seaweed
Laboratory Sample ID: 2407233-01
Report Compiled By: UW BCGF MMRV (Monis, Collier, Johnson)

Table 1. Seaweed elemental analysis

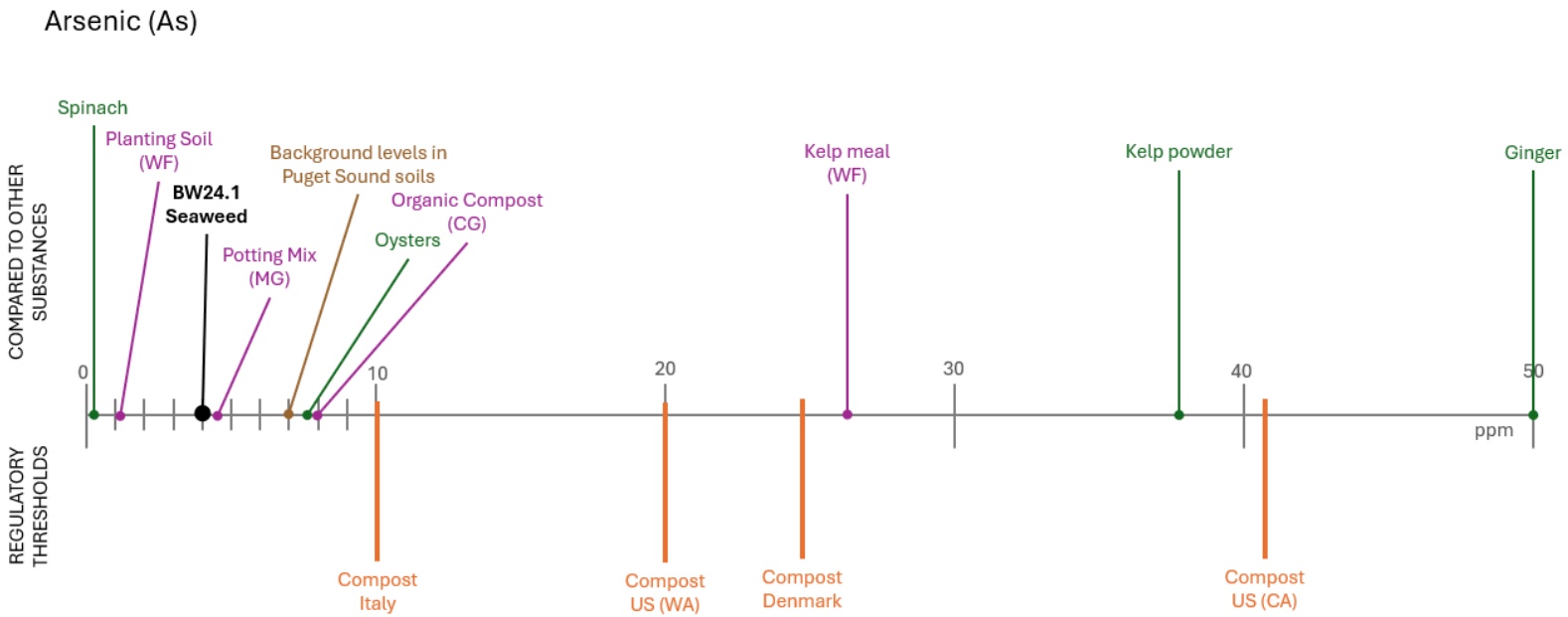
Element	**ppm (mg/kg)**
Arsenic (As)	4
Cadmium (Cd)	0.346
Lead (Pb)	1.2
Mercury (Hg)	0.0091

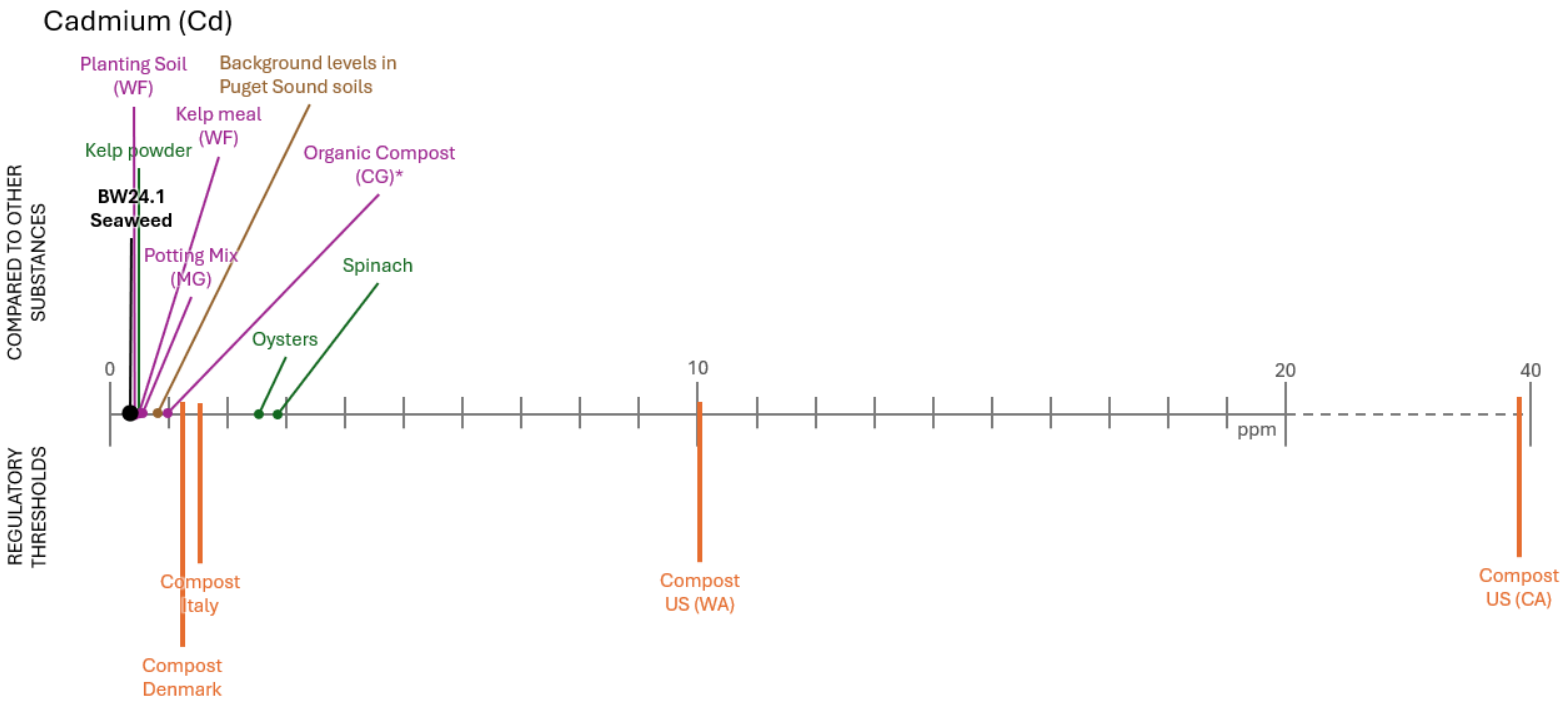
Table 2. Metals application to soils based on BCGF 2024 seaweed application rates

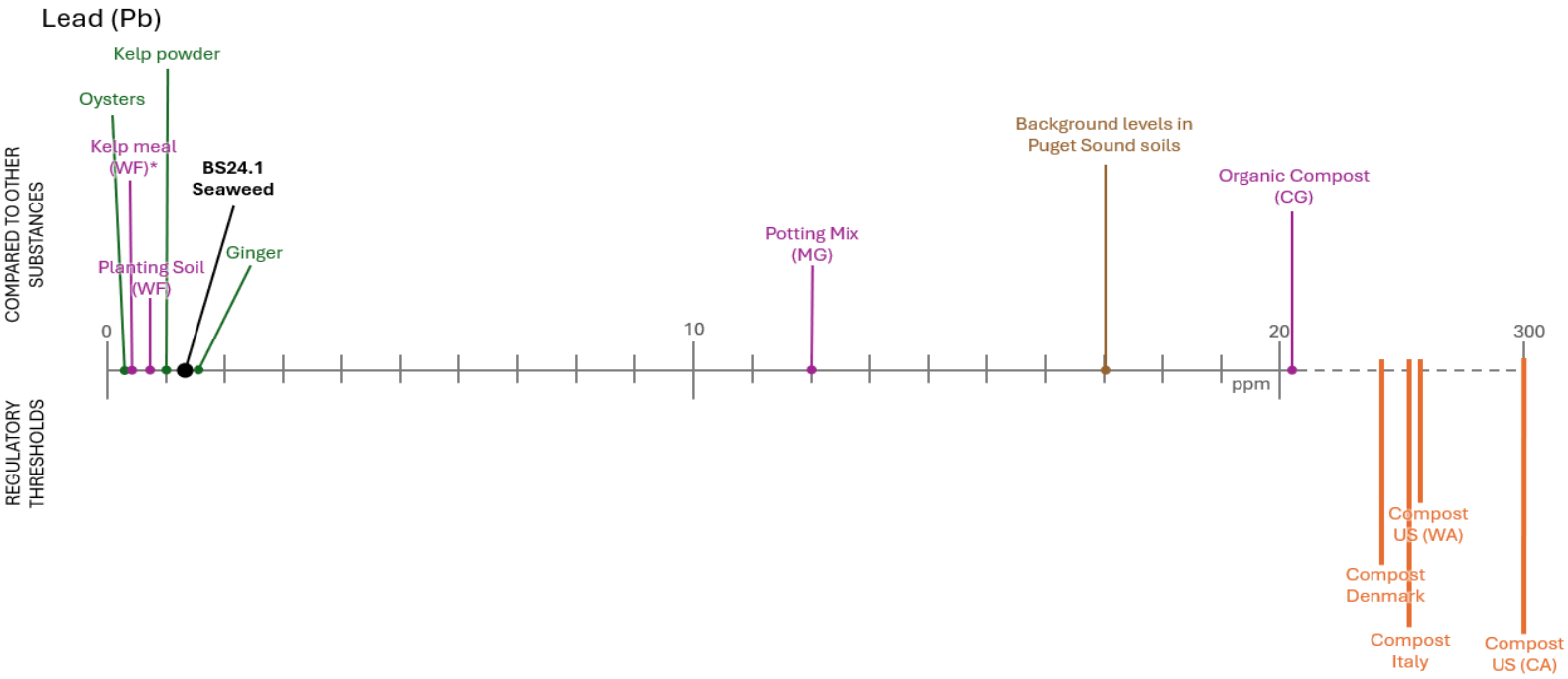
	Tier 2	Tier 3				Washington standards for metals
		Rate A	Rate B	Rate C	Rate D	
Element	---------- lb/ac ----------					lb/ac/yr
Arsenic (As)	0.14	0.07	0.14	0.2	0.27	0.297
Cadmium (Cd)	0.01	0.006	0.01	0.02	0.02	0.079
Lead (Pb)	0.04	0.02	0.04	0.06	0.08	1.981
Mercury (Hg)	0.0003	0.0001	0.0003	0.0004	0.0006	0.019

Interpreting metal content

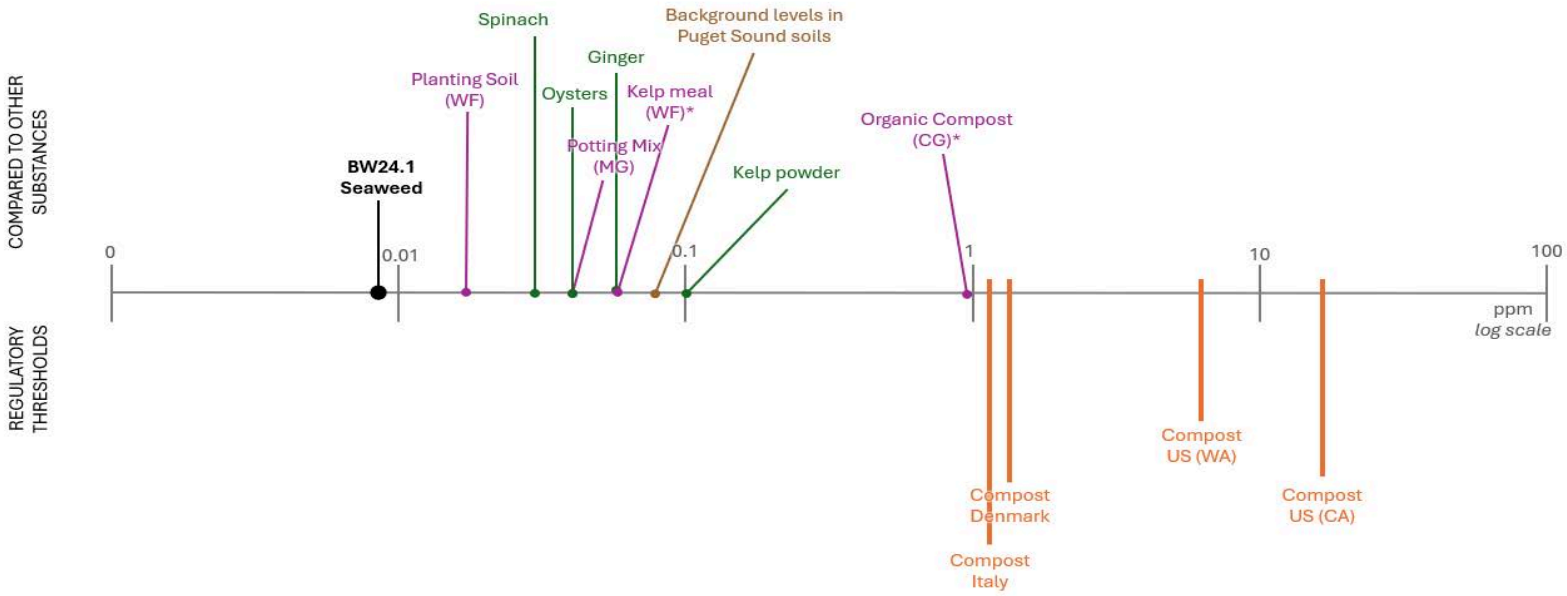
On the next page, the concentrations of As, Cd, Pb, and Hg in BW24.1 seaweed (sourced from Baywater Shellfish farm, Thorndyke Bay, Hood Canal) are shown compared to concentrations from other substances (soils, composts, and foods) and in relation to various regulatory standards for metals levels in soils and composts. The seaweed metals concentrations are within or below the ranges seen in typical commercial composts (Figure 1, compare also to Malone et al., 2023). Seaweed metal concentrations are well below Washington State and international thresholds for composts (Figure 1). In Table 2
above, seaweed application rates for Tier 2 and Tier 3 participating farms are translated into pounds per acre of metals, and checked against Washington State standards for annual metal applications to soils. All application rates are below regulatory thresholds. Regulatory standards for metal concentrations in composts vary widely (Malone et al., 2023) and are not necessarily developed from a human health perspective. Explicitly health focused metrics (e.g., EPA Regional Screening Levels) evaluate risk based on exposure pathways such as ingestion, which is not advised for this seaweed.




Cadmium (Cd)
COMPARED TO OTHER SUBSTANCES
REGULATORY THRESHOLDS
Planting Soil (WF)
Background levels in Puget Sound soils
Kelp meal (WF)
Kelp powder
Organic Compost (CG)*
BW24.1 Seaweed
Potting Mix (MG)
Spinach
Oysters
0
10
20
40
ppm
Compost Italy
Compost Denmark
Compost US (WA)
Compost US (CA)


Lead (Pb)
COMPARED TO OTHER SUBSTANCES
REGULATORY THRESHOLDS
Kelp powder
Oysters
Kelp meal (WF)*
BS24.1 Seaweed
Ginger
Planting Soil (WF)
Potting Mix (MG)
Background levels in Puget Sound soils
Organic Compost (CG)
0
10
20
300
ppm
Compost US (WA)
Compost Denmark
Compost Italy
Compost US (CA)

Mercury (Hg)


COMPARED TO OTHER SUBSTANCES
REGULATORY THRESHOLDS
BW24.1 Seaweed
Planting Soil (WF)
Spinach
Oysters
Ginger
Potting Mix (MG)
Kelp meal (WF)*
Background levels in Puget Sound soils
Kelp powder
Organic Compost (CG)*
Compost US (WA)
Compost Denmark
Compost Italy
Compost US (CA)
0
0.01
0.1
1
10
100
ppm
log scale