Shellfish and Seaweed Species and Gear Thresholds for Alaska Mariculture

Prepared by Bobbi Hudson, Kalloway Page, Tiffany Stephens and Andrew Suhrbier

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Pacific Shellfish Institute
120 State Avenue #1056
Olympia, Washington 98501
www.pacshell.org

Background

The Pacific Shellfish Institute (PSI) was tasked by NOAA Fisheries and the Alaska Regional Aquaculture Coordinator to provide an updated status of Alaska mariculture activities and priority areas to support the advancement of sustainable opportunities in the state. This report aims to help inform NOAA's Aquaculture Opportunity Area (AOA) designation in Alaska. Information contained in this report was gathered through informal surveys and conversations with current Alaskan shellfish and seaweed farmers, and personal observations on Alaska mariculture farms. We have also consulted with shellfish and seaweed producers, extension agents, and trade associations to characterize existing mariculture operations across the U.S.

This report is organized into two sections, and three appendices:

1) Current status of species cultivated in Alaska
    a. Shellfish: cultivation gear and lessons learned
    b. Seaweed: cultivation gear and lessons learned
2) Emerging mariculture species of interest

Appendix A - Commercial U.S. Mariculture Species, by State
Appendix B - Commercial U.S. Mariculture Cultivation Method, by Species
Appendix C - Thresholds by Cultivation Method and Species

1. Current status of species cultivated in Alaska

The Alaska Department of Fish and Game (ADFG) designated four regions within the state to manage fisheries and mariculture activities: Southeast, Southcentral, Westward, and Artic-Yukon-Kuskokwim. However, no mariculture activities are currently occurring within the Artic-Yukon-Kuskokwim region. Average depth of aquatic farm sites does not vary significantly by region (Table 1). The bulk of aquatic farms are sited in marine waters 15 feet or less in depth (Figure 1). Across all regions a total of 1,139 acres are listed as currently active. The vast majority of these parcels are approved via aquatic farm permits, however there are a few hatchery and nursery operations speckled across the state. Southcentral and Westward regions show seaweed-only farms representing most of the permitted acres, while in the Southeast, the region with over half of the total acres of Alaska, invertebrate-only farms have the biggest footprint. There are no invertebrate-only farms currently permitted in the Westward region (Table 2). We also note that hardening areas may be currently underrepresented, despite their importance as pre-harvest areas for shellfish production. Permits show that only 13 parcels are actively listed for hardening in the Southcentral region and 14 parcels for the Southeast region.

Table 1. Depth (ft) of Alaska aquatic farms by region.

Region	Max Depth	Min Depth	Average Depth
Southcentral	-51.4	-0.2	-17.1
Southeast	-46.6	-0.3	-13.7
Westward	-41.2	-1.6	-13.7

Data from Alaska Department of Natural Resources (DNR).

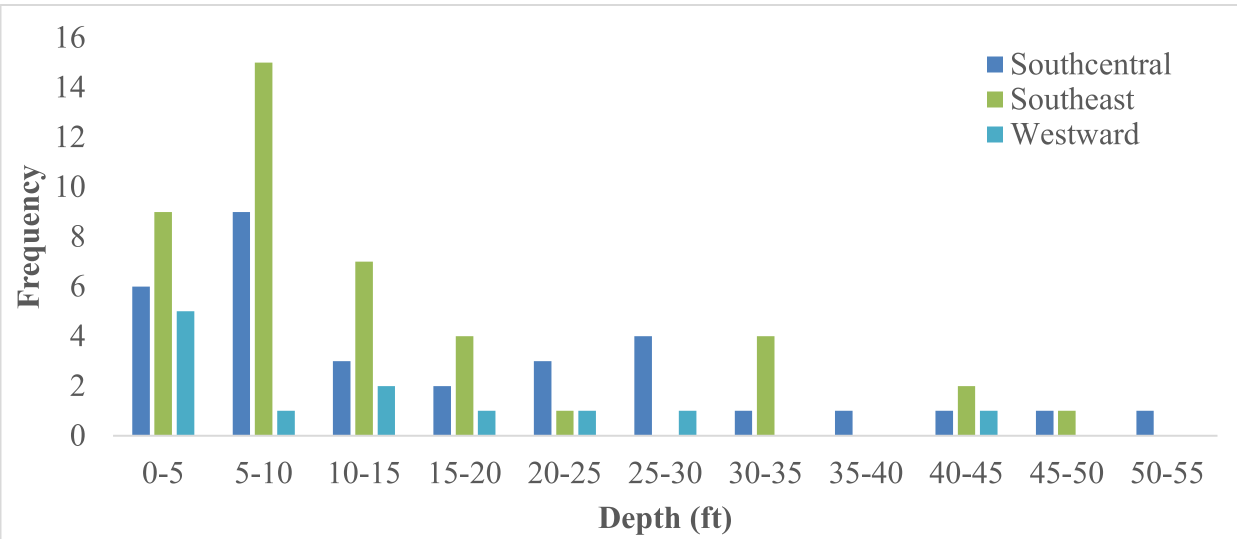


Figure 1. Active aquatic farm depths by region. *Data from Alaska DNR*.

Table 2. Acres permitted for mariculture of invertebrates and seaweed in Alaska, by region.

	Aquatic Farm Permit	Hatchery Permit	Nursery Permit	Grand Total
Southcentral	**221.17**	**0.05**	**0.03**	**221.25**
Invertebrates Only	55.05		0.03	55.08
Seaweed and Invertebrates	40.97	0.01		40.98
Seaweed Only	125.15	0.04		125.19
Southeast	**609.62**	**0.12**	**0.18**	**609.92**
Invertebrates Only	253.9		0.18	254.08
Seaweed and Invertebrates	167.29	0.11		167.4
Seaweed Only	188.43	0.01		188.44
Westward	**307.64**	**0.04**		**307.68**
Seaweed and Invertebrates	102.45			102.45
Seaweed Only	205.19	0.04		205.23
Grand Total	**1138.43**	**0.21**	**0.21**	**1138.85**

Data from Alaska DNR.

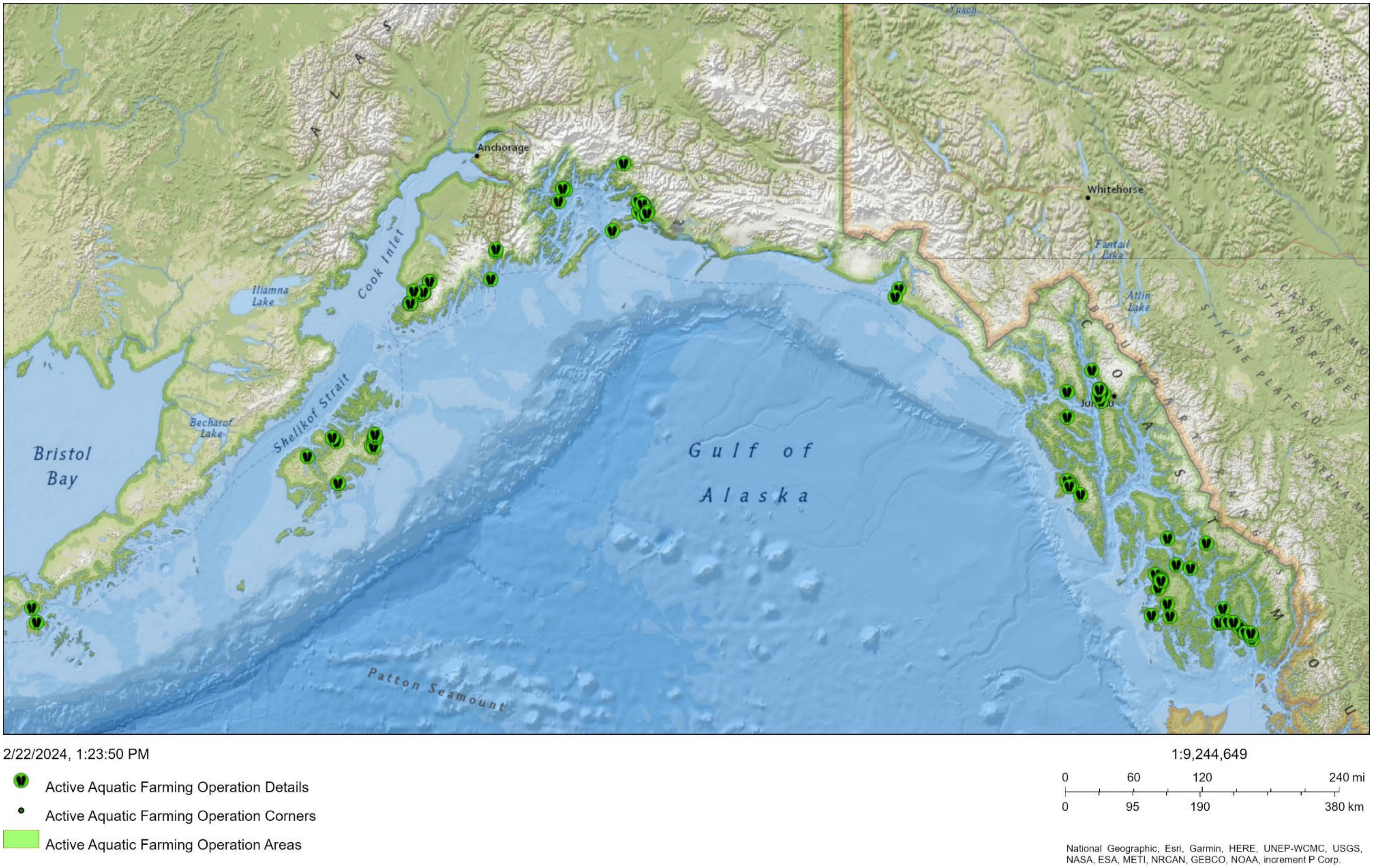


Figure 2. Aquatic farms permitted for 2023 operations in Alaska, including Southeast, Southcentral and Westward. ADF&G web map, at: https://adfg.maps.arcgis.com/apps/webappviewer/index.html?id=f3ca95493c1042b39e42a3ecb5dcad6a&_ga=2.202085393.1217511019.1712002811-259338087.1708767808.

There are currently 19 species of invertebrates permitted across the three Alaska regions with the top three being Pacific oysters (*Crassostrea (Magallana) gigas*), Blue mussels (*Mytilus trossulus*), and geoduck clams (*Panopea generosa*). Other less common invertebrates included Kumamoto oysters (*Crassostrea sikamea*), green, purple, and red urchins (*Strongylocentrotus droebachiensis*, *S. purpuratus,* and *Mesocentrotus franciscanus* respectively), Giant California sea cucumber (*Apostichopus californicus*), various scallop species, cockles (*Clinocardium nuttallii*), and littleneck clams (*Leukoma staminea*). Additional species are currently permitted for Alaska hatcheries but were excluded from the above count due to their permitting being primarily research in nature and not representative of current commercial interests. These include red king crab (*Paralithodes camtschaticus*), blue king crab (*P. platypus*), Pacific razor clams (*Siliqua patula*), Pinto abalone (*Haliotis kamtschatkana*), and butter clams (*Saxidomus gigantea*).

To our knowledge, of all invertebrate species permitted for Alaska mariculture, only three species, all bivalves, are actually being grown to market size and sold to wholesalers or direct to consumers: Pacific oysters, mussels, and geoduck. Including hatcheries, there are 18 species of seaweed currently permitted across the three Alaska regions with the top three being sugar kelp (*Saccharina latissima*), ribbon kelp (*Alaria marginata*), and bull kelp (*Nereocystis luetkeana*). Other recurring species include dulse (*Pulmaria hecatensis* and *Pulmaria mollis*), three ribbed kelp (*Cymathere triplicata*), five ribbed kelp (*Costaria costata*), and black seaweed- nori (*Pyropia abbottiae*).

1a. Bivalves: cultivation gear and lessons learned

Through an informal survey and personal observations, we confirmed a handful of manufactured gear types in use on Alaska shellfish farms. Currently, the vast majority of oyster farms are using stacked wire-mesh trays hanging from rafts or longlines. Among those using wire-mesh, all surveyed farmers indicated they source their trays from Aqua-Pacific Wire Mesh and Supply in Nanaimo, British Columbia (BC), Canada. One oyster farm converted to Hexcyl (Australia) baskets hung from drop lines (single) approximately five years ago. At least two farms are using a combination of containers from Hexcyl (including the FlipFarm system) and Seapa (Australia). One farm indicated a preference for the Seapa

Figure 3. An oyster raft (left) in southeast Alaska and Aqua-Pacific Wire Mesh cages (center) hung in stacks of ten below the raft. Sorting oysters on a southcentral Alaska oyster farm (right) with extruded plastic high-flow cages by Thunderbird Plastics. Photo credit: Bobbi Hudson, PSI.

containers for growout and is pleased with oyster growth and quality—especially shape, using this gear. This farm is also using stacks of high-flow trays, sourced from Thunderbird Plastics (Burnaby, BC), suspended from longlines. Although no other farmers we spoke to indicated use of Thunderbird Plastics high-flow trays, we expect a small number of Alaska oyster farmers are also using this gear.

All survey respondents who indicated they had tried other gear but discontinued it specifically referenced lantern nets, citing "too difficult to work" and "sea otter predation" as the primary reasons for discontinuing use. At least one farm uses lantern nets to hold seed, especially wild set bivalve species (i.e., scallop species). Although they were not represented in the survey responses, it is common knowledge that many oyster farms in the Kachemak Bay area, in Southcentral Alaska, continue to use lantern nets. Some have reported problems with sea otter predation and damage to gear. We hypothesize that these farms operate at a small scale that makes investment in new growout gear impractical.

Recent reviews of production cost for installation and maintenance of various oyster gear types indicate that substantial investment is necessary (Table 3). Across various gear types, large-scale oyster farms were more productive, producing as much as double the number of oysters per hectare when compared to small and medium-scale oyster operations (Engle et al. 2022). For established off-bottom farms, profitability was greater with shorter grow out time to market, while the relationship between productivity and profitability was less clear on startup farms (Engle et al. 2022). Of significance to Alaska mariculture, these findings of greater profitability for faster growth rates are a difficult reality given Alaska's cooler water temperatures compared to other shellfish producing regions. Water temperature is the best proxy for oyster and other bivalve species' growth, and temperature correspondingly predicts seasonal food availability.

Table 3. Installation cost for floating oyster gear systems (from Horwedel and Wellman 2023).

Gear Type	Costs (2023)	Oysters Grown
Flip Farm	$110, 400 USD	360k oysters
Seapa - Adjustable Long Line	$150,708 USD	250,000 - 300,000 oysters
Hexcyl	$25,780.64 AUD	161,943 oysters

Since PSI's early 2023 informal survey of Alaskan shellfish farmers, one farm in Southeast began a large installment of OysterGro (New Brunswick, Canada) systems, which is the first at-scale deployment of this gear type in Alaska. To our knowledge, this Southeast Alaska farm is one of only two commercial deployments of OysterGro on the entire West Coast, but the systems are extremely popular in the Gulf and the East Coast of the U.S. and Canada. All of the growout systems described above differ from nursery systems used to "boost" oyster seed prior to transfer to these growout containers. Few farms in Alaska operate FLUPSYs (Floating Upwelling Systems), but two large systems exist in Southeast and others are coming online in both Southeast and Southcentral. Farms which have been in operation for longer durations have used unique, small-scale systems to boost seed. Many were crafted from coated wire mesh (from Aqua-Pacific) or extruded plastic mesh bags (typically high-density polyethylene, or HDPE, often sourced from Norplex in Washington State.)

The limited oyster growout gear in use in Alaska likely represents limited distribution and logistics challenges to the remote, off the road system reality of existing mariculture operations. Despite free distribution of oyster gear for pilot scale trails enabled by NOAA Sea Grant Aquaculture Extension funding in 2015, less than half a dozen farms deployed and trialed the gear. Gear distribution by PSI under the 2015 NOAA Sea Grant Aquaculture Extension funding included two floating containers and Seapa containers without floats (Figure 4). These gears were chosen because of use in other regions of the U.S. and Canada, characterized by deep water (e.g., subtidal) oyster aquaculture production, which differs from the intertidal oyster culture that constitutes the majority of Washington, Oregon and California oyster production.

Among farms who deployed the free oyster gear, only two farms (one in Southeast and one in Southcentral) reported purchasing additional, similar gear to expand use on their farms. One farm reported discontinuing the pilot scale gear because the floating containers could not withstand the wind and current at their site. In this case, the floating gear was lost when it broke away during a storm event. Suspended oyster culture under rafts is suitable at this site, but floating gear was not due to frequent high wind events and the exposure (surface drag) of the floating gear.

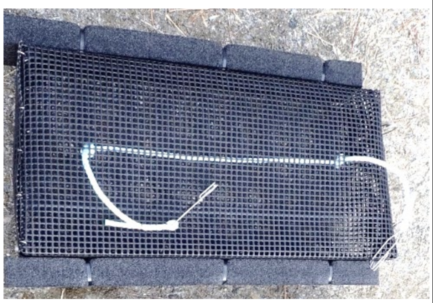
Maine Style Container	**Zapco Bag with Floats**	**Seapa Container**
		
Vexar container with closure 9mm mesh; 29 x 15.5" x 5" deep box Foam floats (or round/square plastic) Hog rings & clips & zip ties *44 per oyster farm*	Vexar bag with closure 10mm mesh; 30 x 18" x 3" deep pouch Foam floats 10mm poly aqualine & assembly *44 per oyster farm*	34L tube with end cap & door 12mm mesh; 33.5" x 10" No floats provided 20mm flexi clip, 11mm clamps & pins *22 per oyster farm*

Figure 4. Oyster gear distributed by PSI for pilot scale trails in Alaska, enabled by NOAA Sea Grant Aquaculture Extension funding in 2015.

One finding of interest with the 2015 pilot oyster gear deployment was sea otter interactions. In Kachemak Bay, in Southcentral Alaska, one shellfish farm discontinued the Zapco style baskets because otters chewed the foam material, damaging the floats and creating the likely possibility of generating marine debris. The farm immediately removed the gear and now avoids any similar foam material for on-water use. While this mammal interaction was not particularly surprising, it was not anticipated by the aquaculture gear manufacturer or distributor. This unanticipated risk validates caution as mariculture gears are deployed in Alaska. As was the case for the 2015 gear distribution, small scale deployment prior to commercial scale application is critical to avoid unanticipated gear loss, and to facilitate individual farms to develop efficient methods to work and maintain gear. Other considerations noted by the 2015 pilot oyster gear deployment was winter surface icing, and surface debris from large tides. Large tidal amplitudes are common to most areas of Alaska. If oysters float too close to the surface they, and the gear containing them, may experience significant surface debris fouling.

This report elucidates the operational depth of existing mariculture farms, and regions currently producing commercial shellfish and seaweeds in Alaska. We also characterize commercial species and cultivation gear throughout U.S. coastal states (Appendix A and B). We do not attempt to characterize the myriad of bottom conditions and oceanographic forces influencing current mariculture operations. The unique nature of individual gear deployment—from anchor style, number of containers per array/longline/dropline, type of and material constituting raft platforms (when used) and connection points—makes specific threshold definition for individual gear types impractical. Aquaculture gear manufacturers recognize limits to gear durability, typically defined by force or tensile strength, and UV resilience of component parts. Gear manufacturers seek to sell durable, easy to use products which will withstand the conditions where they are used. However, manufacturers do not provide specifications that limit use, other than suggested stocking densities (based on volume, e.g. available space) and to make recommendations for connection and/or longline materials or anchoring. Suggestions provided by sales staff are based on expected conditions (i.e., tidal amplitude, currents, wind and waves) reported by the purchasing farmer. For these reasons, it is ultimately up to individual farms to deploy and maintain gear appropriate for their farm sites.

Anchoring requirements for floating installations are dictated by surface area or drag of the system, combined with wind, waves and current. However, mariculture gear losses are commonly the result of chaffing or repeated weakening by small force, causing severing of individual component parts. Chaffing and repeated small force weakening is difficult to predict for floating culture gear because surface area and drag changes depending on buoyancy of the gear and depth above and below the surface. These factors also change over time as the buoyant materials age, the contained animals grow, and "fouling" (non-target organisms attaching to the gear, or the animals themselves). Failures among mariculture gear, especially for shellfish production, are typically partial failures of component parts that results in partial break-up rather than complete catastrophic failure.

1b. Seaweeds: cultivation gear and lessons learned

The expected nutrient load of ambient seawater is a critical consideration for site selection; it is as important as light and temperature, and interacts with the hydrodynamics due to the formation of boundary layers around and within kelp farms and the subsequent transfer of nutrients across those boundary layers. Most farmers do not have access to nutrient data unless directly collaborating on a funded scientific/academic project (i.e. aquarium kits are insufficient for monitoring). At the time of this report, observations of seawater nutrient data in combination with kelp quality (e.g. coloration, frond thickness) and empirical data for %C and %N of kelp tissues for Alaskan farms suggest that nearly all farmers in Alaska experience nitrogen limitation events, which are most pronounced in protected bays or in areas with high water retention. This typically begins to occur after the first phytoplankton bloom in the spring. Work done by the Mariculture Lab at University of Alaska (UAF) College of Fisheries and Ocean Sciences (CFOS) suggests that Prince William Sound may experience chronic low nitrogen events starting as early as April (see Umanzor & Stephens 2022, Stephens & Umanzor 2024); this is also observed in protected bays like Doyle Bay on Prince of Wales Island. Collectively, all available data demonstrate nutrient concerns for most Alaskan farms that are in operation and instead of harvesting in May or June, farms may need to harvest in April when biomass is often lower. Some scaled farming operations in Asia address this concern by adding nutrients to the system, and thus are not "zero-input". This concern may be enhanced as oceanic conditions change (i.e. warm) because phytoplankton blooms may occur earlier, and thus nutrient limitation will occur earlier in prone areas (e.g. protected bays, areas with poor water exchange).

For considering nutrient thresholds for kelps, academic studies suggest kelp productivity is inhibited when seawater nitrate concentrations are 1 μM or lower (Gerard 1982b). Additionally, total tissue nitrogen values of approximately 2% dry weight are critical for sustained growth (Hanisak 1979) and values between 1 to 1.5% dry weight correspond with nitrogen limited growth (Gerard 1982a, Hurd et al. 1996). This can be paired with C:N values, where a ratio value of 15 and higher can indicate nitrogen exhaustion (Hanisak 1983). These relationships, however, can change not only across kelp species but also populations. Stephens 2015, for example, found that a tissue nitrogen content greater than 0.54% in one population of *Macrocysits pyrifera* was necessary for sustained growth, while a population in a different geographical location needed at least 1.52% nitrogen.

The transfer of nutrients and wastes to and from kelp interacts with hydrodynamics. Academic research indicates that a current speed of at least 30 cm/s is necessary to support the sustained growth of some kelps (see Hurd 2000), this is particularly true when ambient nutrients are low because water motion assists in breaking-up boundary layers and increasing the mass transfer of nutrients. Mixed hydrodynamic forces (e.g. oscillatory flow and not just laminar flow) further enhance the mass transfer of nutrients (see Porter et al. 2000). Recent research within the Mariculture Lab at UAF CFOS (Meyer et al. unpublished, Stephens et al. unpublished) has identified that the distance between grow lines has a significant influence on the yield of kelp per ft of grow line, largely because of this interaction between nutrients and hydrodynamics.

Currently, kelp biomass across most Alaska farms is grown at a fixed depth (relative to the surface) of 5-10 ft; some bull kelp farming is not at a fixed depth, where grow lines are lowered throughout the season down to about 15 ft. Light attenuation and the presence of a freshwater lens can drive decisions around specific depth for each farm. Kelp need light to trigger development/growth, their biological limit is deeper than where farmers tend to place their lines, which is meant to maximize productivity. As for salinity, the depth threshold should take the average depth of the freshwater lens into account (often not deeper than 4-5 ft if a lens is normal in bays that have input from streams that are small/ moderate in size; *T. Stephens pers. obs.*); *Saccharina latissima* does worse when exposed to freshwater than *Alaria marginata* and *Nereocystis luetkeana* due to their natural history.

Line spacing is highly variable across existing farms, ranging from 2 ft to more than 15 ft. Line spacing/density can influence the biomass, particularly when ambient seawater nutrients are low. Higher line density can result in less total farmed biomass, as can limiting the number of lines deployed by increasing the spacing between lines in a fixed space. There is no "best" spacing, it will depend on the local environment (nutrients, current speed, waves) so it is difficult to establish a threshold. Generally, spacing smaller than 4 ft may be too tightly packed and spacing larger than 10-15 ft may be unnecessary from the perspective of increasing yields. Spacing decisions may be modulated by species cultivated; e.g. *Saccharina latissima* will grow better at high density than *Nereocystis luetkeana* (in the environmental conditions that farmers are currently cultivating).

The lack of knowledge about the forces that act upon a kelp array (e.g. current strength and drag load) has resulted in some farms with over- and under-engineered anchoring systems. Over-engineered systems can incur substantial, unnecessary cost to a farmer via cost of resources and cost of installation. Under-engineered systems may result in lost gear or needing to harvest early because drag forces on mature kelp may be stronger than anchor holding power (loss in potential revenue).

A handful of active farms and test farms have experienced anchor drag, often starting in April or early May, when kelp biomass has matured and when regional tidal exchanges begin to increase in strength. Working with a hydrodynamics modeler is an option but not inherently less risky. For example, one farm hired a modeler/engineer to consult on an array design and ultimately over-engineered the system due to not having adequate current data. The farmer and modeler relied on the closest current/wave buoy and ultimately built and installed an anchoring system that was at least 4x more robust than needed. This cost was magnified by the size of ships/barges and personnel needed for deployment; costs for deployment were non-linear to cost of gear. However, as the industry matures, this will become less of a concern.

Anchor type is a critical consideration, in-step with bottom type. Currently, all farmers in Alaska are using above-ground anchors, as opposed to sand screw/helical or pin anchors. This decision is easily made because deploying a steel or concrete anchor over the side of the boat is generally cheaper (up-front) and more familiar to farmers, as opposed to sand screw or pin anchors. There is no collective "best" anchoring approach due to the diversity of habitat across Alaska. To streamline installation costs, each farmer needs appropriate resources to understand bottom type, current speed/direction, and wave height.

Other than it being a good idea for farmers to build an array system that would withstand a 100-yr storm, it is difficult to establish thresholds for this category, particularly with diversity of array designs. Most farmers are using the catenary or parabolic arrays (e.g. the Goudey design), so it may be possible to offer an anchoring guide relative to expected current speed for those systems (e.g. focus on needs for one 25-line catenary section with four anchors, the farmer can extrapolate for number of sections).

Catenary arrays by design are taught lines, which reduces entanglement of the grow lines, as well as theoretically reducing the risk of marine mammal entanglement. These arrays also maintain more steady growth depth (i.e. less sagging) as kelp biomass increases over the growing season, with floats or weights added as necessary.

Informal survey of kelp farmers that are commercially active (N = 9) generated Table 4 and the following summary. One additional commercially active farm was not reached.

Kelp Cultivation:

- Cultivation of *Nereocystis* has been attempted by five farms, two of which have discontinued this species (Farms 4,9) and one farm continues to commercially cultivate *Nereocystis* in 2023-2024 season (Farm 6); they are also experimentally cultivating it in partnership with a UAF team to test different depths.
- Two farms did not plan to plant kelp in the 2023-2024 season (Farms 7,8), one relinquished their lease to the State (Farm 8) due to available bandwidth, cost of farming, and lack of market.
- Two farms are interested in commercially cultivating *Nereocystis* for the first time (Farms 1,2), one of which has partnered with UAF for the 2023-2024 season to test the effect of different seeding strategies on the density of *Nereocystis* (Farm 1).
- One farm stopped cultivating *Alaria* because ambient nutrients were not high enough to support a quality crop (Farm 4). A second farm also did not plant *Alaria* in the 2023-2024 season due to inadequate environmental conditions for their farm and lack of market (Farm 9).
- Farmers that sourced their seed from Blue Evolution's kelp hatchery on Kodiak Island are securing new relationships with other nurseries for seed production (i.e. Alutiiq Pride in Seward, UAF-CFOS in Juneau).

Kelp Farming Infrastructure:

- Anchor drag was reported by three farms. Two farms likely due to interactions with the drag imposed upon the system after kelp began to grow, the third likely due to the slope of the bottom. Anchors were cement blocks and steel navy-style anchors.
- Tri-pod system was discontinued by one farm as not appropriate for commercial farming.
- One farm specifically cited that the practice and gear associated with sinking *Nereocystis* was not ergonomically or fiscally feasible for their commercial operation, the method of transporting and attaching concrete blocks was discontinued along with the species.
- One farm attempted to use crab pot clips to attach buoys that keep the grow line at a steady depth relative to the surface, the use of this gear was discontinued because the clips malformed under prolonged buoy line tension/strain.

Table 4. Farming details (i.e. array design, species cultivated, line depth/distance, key timing windows) for surveyed kelp farms.

Farm #	Port	Farming array	Kelp species	Depth / spacing of growling	Month healthiest	Month harvest	Hatchery
1	Kodiak	Catenary	*Alaria*, *Saccharina* (experimental *Nereocystis*)	8 ft / 4 ft	mid-Apr early June	mid-Apr to mid-May mid-Apr to late Jun	Their own, Blue Evolution
2	Kodiak	Catenary	*Saccharina* (wants to grow *Nereocystis*)	8-10 ft / 5 ft	Apr to early May	May to early Jun	Alutiiq Pride
3	Kodiak	Single-line (changing to catenary)	*Saccharina* (will grow *Alaria* next year)	n.a	Late Apr to early May	May	Alutiiq Pride
4	Cordova	Single-line, catenary, multiline spreader bar	*Saccharina*, *Nereocystis* (discon.)	8-10 ft / 2-3 ft	April	April	Aluutiq Pride, PWS Hatchery
5	Kachemak Bay	Alternative: collects set on oyster gear	*Costaria*, *Saccharina* *Hedophyllum*, dulse	n.a	Into early summer	Harvest year-round (excluding Aug, Sep)	n.a, wild set
6	Juneau	Catenary	*Nereocystis*, *Saccharina*	8-10 ft / 5 ft	Early to mid-May	Late Apr to early Jun	Alutiiq Pride, Research partners
7	Juneau†	Single-line	*Nereocystis*, *Saccharina*	10 ft / n.a	Late Apr	Late Apr to early May	Blue Evolution
8	Petersburg	Catenary	*Nereocystis*, *Saccharina*	6-10 ft / 5-20 ft	Apr	Late Apr to early May	Mother of Millions
9	Craig	Catenary	*Alaria* (temp. discon.), *Saccharina, Nereocystis* (discon.)	5-12 ft / 10 ft	Apr	Late Apr to early May	Previously w/ Oceans Alaska; building their own for 2024-2025.

† Farm is not operating in 2023-2024.

2. Emerging mariculture species of interest

Candidate invertebrate and seaweed species for mariculture are limited to species native to the state of Alaska, due to existing restrictions on cultivation of non-native species. The exception is "Pacific" oysters, which has been interpreted by ADFG to include both Pacific oyster (*Crassostrea (Magallana) gigas*) and Kumamoto oyster (*C. sikamea*) to present but could also include Eastern oyster (*C. virginica*) of Pacific origin (e.g. West Coast farmed, or West Coast hatchery produced). Currently, no farms have requested *C. virginica* imports and certified seed providers do not have *C. virginica* available for sales in Alaska (www.adfg.alaska.gov/index.cfm?adfg=aquaticfarming.seed_sources). Below, we briefly summarize status of promising species that have been explored for cultivation in Alaska.

All species are susceptible to the risks of changing oceanic conditions, which could limit food availability, or increase food availability and growth rate with warming temperatures. However, changing ocean conditions could also increase harmful algal bloom (HAB) frequency and duration, which is especially concerning for paralytic shellfish toxins. Warming ocean temperatures also has implications for naturally occurring viruses that proliferate in warmer conditions, such as *Vibrio parahaemolyticus* (Vp). Vp has not historically been a problem in Alaska, but it is a notable source of illness from raw consumption of shellfish grown in BC, Washington State, and elsewhere during the warmer, summer months. Fecal coliform bacteria is also not currently a significant issue at the vast majority of Alaska's mariculture farms, but anthropogenic inputs and changing populations or movement patterns of other mammals could negatively impact water quality to a point where maricultured products are not safe for human consumption in some areas.

Sea cucumber harvest in Southeast Alaska has increased in recent years, approaching 2 million pounds per year. Prices dropped during the pandemic but exceeded $5/pound during the prior three years, with strong demand from Asia (ADFG, 2022). Efforts to farm this species are still in the experimental stage in Alaska, BC, and Washington. A Pacific States Marine Fisheries Commission grant led by PSI is exploring improved nursery feeding techniques at the Alutiiq Pride Marine Institute hatchery. This study hopes to create a seed conduit from Seward, in Southcentral Alaska, by transferring nursery growout technology to a major harvest and processing hub, Ketchikan, in the southeast. Research has also documented natural settlement of sea cucumbers on oyster gear, especially tray systems in the southeast, and explored growout with food sources (i.e. FLUPSYs and oyster farms).

Successful commercial mariculture of sea cucumber is likely contingent on the establishment of a dedicated hatchery and nursery in southeast Alaska. Outplants of juveniles need to be tagged and kept in cages to retain "positive control" per ADFG Aquatic Farm regulations. A 2019 feasibility study conducted by the McDowell Group and Dr. Charlotte Regula-Whitefield for the Southeast Alaska Regional Dive Fisheries Association (SARDFA) considered the costs and return on investment for a hatchery and tray system growout facility near Ketchikan, but was ultimately found inconclusive (Whitefield, 2019).

Purple hinge rock scallop (*Crassadoma gigantea*) is a promising native species for aquaculture production, with strong market potential and substantial interest by the shellfish industry because of the adductor muscle size and quality. A serious issue with rock scallop aquaculture potential was the lack of information on biotoxin retention and detoxification. Rock scallops can retain high levels of paralytic shellfish toxins (PST), including saxitoxin and derivatives, in both the visceral tissue and in the adductor muscle. Recent assessment of PST in rock scallop tissues from field and laboratory studies revealed very high and persistent levels of PST in visceral tissue and adductor muscle tissue that were beyond the FDA limit (80 μg STX equivalents 100 g^{-1} shellfish tissue) for safe shellfish consumption (Houle et al. 2023). Comprehensive PST testing of rock scallop adductor muscles at harvest time will be critical prior to commercial sale and consumption of this species (Houle et al. 2023).

Littleneck clam (*Leukoma staminea*) culture and research has been active for 20 years in Alaska. The Chugach Regional Resources Commission (CRRC) has been producing littleneck clams for enhancement projects in Resurrection Bay, Seldovia and Port Graham in southcentral Alaska. Alutiiq Pride Marine Institute (APMI), operated by CRRC, planted littleneck clams in Prince William Sound in 2021-2023 and has plans to continue development of hatchery and out-planting techniques in collaboration with area tribes. CRRC was formed in 1984 when the seven Tribes of the Chugach Region--Chenega, Eyak (Cordova), Nanwalek, Port Graham, Qutekcak (Seward), Tatitlek, and Valdez--established the long-range goal to “promote Tribal sovereignty and the protection of our subsistence lifestyle through development and implementation of Tribal natural resource management programs to assure the conservation, sound economic development, and stewardship of the natural resources in the traditional use areas of the Chugach Region.”

Issues regarding predation, specifically from otters and sea stars, remain. Natural populations have declined so much that enhancement is warranted. APMI has adapted its culture systems and strategies to produce 8mm+ seed during 9 months in the hatchery. However, seed production is expensive and may be cost prohibitive for aquatic farming. Seeding with 8mm seed or larger has increased grow out success and reduced growout time of a mature 30mm clam from 6 to 4 years. Predator control methods that are successful and manageable in other states could be transferred to Alaska. Seeding and predator control test trials should be the next steps toward mariculture of this species. This would involve testing growth, survival, and maintenance costs and schedules of cleaning off fouling organisms on predator control devices. Market demand also needs to be addressed as most clams (excluding geoduck) harvested on the U.S. west coast are Manila clams (*Ruditapes philippinarum)* due to their longer shelf life. In fact, tribal, commercial and aquaculturists routinely avoid littleneck clams to focus solely on Manilas. In Alaska, the current market value of hardshell clams is less than $.30 each, a low return on investment. There is a need to differentiate the clam to reward a higher price.

Cockle clam (*Clinocardium nuttallii*) aquaculture is in its infancy. Hatchery techniques were successfully established in BC at the Vancouver Island University Deep Bay Research Station but have not advanced. Efforts are currently under way to produce seed and advance nursery and growout in Washington by the Puget Sound Restoration Fund. In Alaska, APMI successfully raised cockles in lantern nets in 2004 and produced cockle seed for local native communities in southcentral Alaska in 2017.

Cockles can be grown on or off bottom in trays, cages, or lantern nets. Current bottlenecks are the lack of a dedicated hatchery, unknowns in farming techniques, and poor shelf life. The cockle can move laterally along beaches via its large foot, adding to challenges to growout and the study of the species. Long term growout studies are needed to target movement, survival, predation, and time to market. To address shelf life, stabilization methods such as canning or freezing need to be explored.

Geoducks (*Panopea generosa*) remain a promising candidate for mariculture development in Alaska. The state manages a robust commercial dive fishery, primarily in southeast, and similar fisheries exist in Washington State and BC. These regions also have substantial geoduck aquaculture operations, on both intertidal and subtidal leases and privately owned aquatic lands. Farming the giant clams began in the 1990s in Washington and in 2000 in Alaska. Live clams reportedly sell for $125 in Asia and farmed geoduck fetch a higher price than wild harvest animals.

Table 5. Geoduck from Alaska aquatic farms.

Year	Pounds Sold
2022	Confidential
2021	Confidential
2020	Confidential
2019	Confidential
2018	Confidential
2017	11,456
2016	42,695
2015	Confidential
2014	Confidential
2013	Confidential
2012	Confidential
2011	6,263
2010	8,446
2009	7,839
2008	9,520
2007	14,374
2006	46,082

ADFG data.

Farmed geoduck production in Washington has increased substantially, and in 2015 accounted for 7% of the total pounds produced and 27% of the total value for the state (Decker 2015). Average price per pound, based on production records submitted to the Washington Department of Fish and Wildlife, was $8.60/lb from 2004–2008 and increased to $13.37/lb for 2009–2013 (Decker 2015). Washington farmers reported 1,613,114 pounds of farmed geoduck sold in 2013, valued at $24,482,209.

ADFG indicated no farmed geoduck production through 2006 from 18 permitted farm sites totaling 133 acres (Pring-Ham 2006). Production was reported in 2011 and 2012, and cumulative aquatic farm sales between 2008-2012 was $13,356 (Josephson & Pring-Ham 2013). In 2017, 11,181 pounds of geoduck were produced by 4 operations, representing a 74% decrease from the prior year (Pring-Ham 2018). Subsequently, available data has been withheld due to confidentiality and reported data group geoduck and other clam harvests (littleneck) together on aquatic farms (Table 5).

Geoduck larvae are raised in hatcheries to ~1-3mm. Alaska seed sources shipped 194,000 geoducks to 9 aquatic farm operations in 2014 (Pring-Ham & Politano 2015). Peak acquisition by aquatic farms was in 2007, and in-state seedstock acquired by both hatchery and nursery operations in 2014 totaled 2.5 million, representing an 844% increase (Pring-Ham & Politano 2015). Considerable effort has been made to advance hatchery production of geoduck in Alaska, most recently in 2017-2019 with NOAA funding (NA17OAR4170231) to OceansAlaska and APMI, partnered with SARDFA and Alaska Sea Grant. Technology transfer for spawning, larval transfer, larval setting, and juvenile rearing resulted from the research and in June and July 2019, ~14,500 geoduck of 3-6mm and larger (10-25mm) were provided to 4 aquatic farms permitted for geoduck culture (Freitag et al. 2019). PSI interviewed a recipient farm who reported little, if any, of the geoduck survived outplant.

This recent research indicates geoduck can be successfully spawned and maintained in nursery systems in Alaska, but considerable work remains to produce seed of a size and quality for successful mariculture expansion. Substantial effort in the past decade has produced larger, higher quality seed for Washington and BC shellfish farmers, where mariculture expansion has been achieved. In addition to hatchery and nursery innovations resulting in larger seed (6mm+), Washington farmers report higher rates of seed survival after outplant and faster growth resulting in a shorter growout cycle. Farm managers attribute improved survival to a variety of new predator exclusion devices, and improved planting techniques. Some farmers consider their practices proprietary, but a few are willing to share information. Effective collaborations or business partnerships with experienced geoduck farmers will likely be required for Alaska to realize its potential for geoduck mariculture expansion.

Giant kelp (*Macrocystis tenuifolia*) is an upcoming crop for commercial farmers in Alaska, driven by ambitions of two scaled companies that anticipate success in permitting leases on west Prince of Wales Island in 2024 and south of Ketchikan (Duke Island) in 2025 (i.e. Kelp Blue and Pacific Kelp Co., respectively). *Macrocystis* has been wild-harvested at scale in California since the 1950's and farmed in Chile since the 1980's, however farming in Chile didn't begin to scale until about 1999 when increased abalone farming demanded higher kelp production. Broadly, the markets for farmed *Macrocystis* products are similar to other kelp crops and include food additives, agrochemicals, cosmetics, and pharmaceuticals, with growing interest in bioplastics, biofuels, and textiles. If their permits are approved, Kelp Blue has confirmed markets for agrochemicals and Pacific Kelp Co. has confirmed markets for bulk dried flake. It should be noted that, recently, giant kelp north of Point Conception, California, was determined to be a different species than found south of that headland and in the Southern Hemisphere.

Other kelp species are also of consideration but are not commercially cultivated elsewhere. Dragon kelp (*Eularia fistulosa*) is of interest due to flavor profiles, where the value-added company Barnacle Foods describes it having a strong umami flavor, almost like a teriyaki (*T. Stephens, pers. comms*.). Lastly, there is interest in the commercial cultivation of split kelp (*Hedophyllum nigripes*) because it is a cosmopolitan species that grows in relatively high biomass in Southeast Alaska. Interestingly, tissue analysis conducted by an anonymous biomaterials company determined that this species has a higher dry to wet weight ratio relative to other kelps and may have a higher proportion of a specific carbohydrate that they are interested in, which could improve efficiencies in farming and extraction. Via a collaborative project funded by the Alaska Mariculture Cluster, both dragon kelp and split kelp will be cultivated to determine feasibility in farming and yield (i.e. Kodiak Archipelago Leadership Institute, Alaska Ocean Farms, Kelp Line LLC).

As for red seaweeds, Pacific dulse (*Develaraea mollis*) and stiff red ribbon dulse (*Palmaria hacatensis*) have been experimentally cultivated in Juneau via land-based tumble culture. The latter is unlikely to be commercially feasible at this time due to biological constraints in artificial systems, but the former is commercially cultivated in California and Oregon at small scale – this biomass enters food systems due to the flavor and protein content. Recently, a project was awarded to the Mariculture Lab (UAF CFOS; Umanzor, Stephens, Dittrich) to write a cultivation manual for *D. mollis*, scheduled to be completed in 2025. Similarly, black seaweed (*Pyropia abbottiae*), a close relative to Nori, is of interest due to flavor and protein profiles. Black seaweed, however, is commercially problematic because the life cycle has not been repeatedly/reliably closed in lab settings despite several attempts by different teams and because there is limited support in Alaska due to cultural sensitivity in the commercialization of this species.

Conclusion

This report elucidates the operational depth of permitted mariculture farms, and regions currently producing commercial shellfish and seaweed. Informal surveys and conversations with current shellfish and seaweed farmers revealed few species under active cultivation. For shellfish, few cultivation gear types are in use, and suitability of each gear type has largely been derived through trial and error. Anchoring requirements for floating installations are dictated by surface area or drag of the system, combined with wind, waves and current. For floating culture gear, surface area and drag changes over time and depending on buoyancy of the gear, and depth above and below the surface. The unique nature of individual gear deployment—from anchor style, number of containers per array/longline/dropline, type of and material constituting raft platforms (when used) and connection points—makes specific threshold definition for individual gear types impractical. It is ultimately up to individual farms to use gear appropriate for their farm sites. As was the case for the 2015 pilot oyster gear distribution, small scale deployment prior to commercial scale application is critical to avoid unanticipated gear loss, and to facilitate individual farms to develop efficient methods to work and maintain gear.

For seaweed, nutrient load of ambient seawater is perhaps the most important variable for site selection; and interacts with temperature and hydrodynamics. Seawater nutrients are depleted by phytoplankton blooms, and nutrient limitation will always be a factor for farmers in a zero-input system. Farmers currently do not have access to nutrient data unless directly collaborating on a funded research project. Finally, the lack of knowledge about the forces that act upon a kelp array (e.g. current strength and drag load) has resulted in over- and under-engineered anchoring systems on some farms in Alaska. Over-engineered systems can incur substantial, unnecessary cost to a farmer while under-engineered systems may result in lost gear or needing to harvest early because drag forces on mature kelp may be stronger than anchor holding power.

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Appendix A. Commercial U.S. Mariculture Species, by State

	Atlantic Region													
Species	**ME**	**NH**	**MA**	**RI**	**CT**	**NY**	**NJ**	**DE**	**MD**	**VA**	**NC**	**SC**	**GA**	**FL**
Pacific Oyster														
Eastern Oyster	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Kumamoto Oyster														
Olympia Oyster														
European Flat Oyster	X		X											
Suminoe Oyster														
Hard Clam	X		X	X	X	X	X	X		X	X	X	X	X
Manila Clam														
Geoduck Clam														
Soft-Shell Clam			X						?					
Atlantic Surf Clam			X	X										
Sunray Venus Clam											X			X
Butter Clam														
Mediterranean Mussel														
Blue Mussel	X	X		X	X	X								
Bay Mussel														
Bay Scallop	X		X	X	X	X								
Atlantic Sea Scallop	X													
Purple Hinge Rock Scallop														
Pacific Weathervane Scallop														
Japanese Scallop														
Abalone														
Pacific Razor Clam														
Atlantic Razor Clam														
Blood Ark			X											
Ponderous Ark														
Ocean Quahog														
Queen Conch														
Giant Sea Scallop	X													
Cockles														
Native Littleneck														
Savory/Varnish														
Horse Clam														

Appendix A. Commercial U.S. Mariculture Species, by State

	Pacific + Islands Regions					Gulf of Mexico Region				
Species	**AK**	**OR**	**WA**	**CA**	**HI**	**FL**	**AL**	**MS**	**LA**	**TX**
Pacific Oyster	X	X	X	X	X					
Eastern Oyster			X	X	X	X	X	X	X	X
Kumamoto Oyster		X	X	X	X					
Olympia Oyster		X	X	X	X					
European Flat Oyster				X	X					
Suminoe Oyster										
Hard Clam					X	X				
Manila Clam			X	X	X					
Geoduck Clam	X		X							
Soft-Shell Clam			X							
Atlantic Surf Clam										
Sunray Venus Clam						X				
Butter Clam			X							
Mediterranean Mussel			X	X	X					
Blue Mussel					X					
Bay Mussel	X		X							
Bay Scallop										
Atlantic Sea Scallop										
Purple Hinge Rock Scallop			X							
Pacific Weathervane Scallop			X							
Japanese Scallop										
Abalone				X	X					
Pacific Razor Clam										
Atlantic Razor Clam										
Blood Ark										
Ponderous Ark										
Ocean Quahog										
Queen Conch										
Giant Sea Scallop										
Cockles			X							
Native Littleneck			X							
Savory/Varnish			X							
Horse Clam			X							

Appendix A. Commercial U.S. Mariculture Species, by State

	West Coast					East Coast					
Species	**AK**	**WA**	**OR**	**CA**	**HI**	**ME**	**NH**	**MA**	**RI**	**CT**	**NY**
Sugar Kelp (*Saccharina latissima*)	X	X				X	X	X	X	X	X
Winged Kelp (*Alaria esculenta*)						X					
Skinny Kelp (*Saccharina angustissima*)						X					
Gracilaria (*Gracilaria tikvahaie*)										X	X
Ribbon Kelp (*Alaria marginata*)	X										
Bull Kelp (*Nereocystis luetkeana*)	X										
Dulse (*Palmaria palmata & P. mollis*)		X	X	X							
Turkish Towel (*Chondracanthus spp*.)		X									
Sea Lettuce (*Ulva spp.)*		X		X							
Red Ogo (*Gracilaria pacifica*)				X							
Limu Manauea (*Gracilaria spp.*)					X						
Limu Kohu (*Asparagopsis taxiformis*)					X						
Lepe`ula`ula (*Halymenia Formosa*)					X						

Appendix B. Commercial U.S. Mariculture Cultivation Method, by Species

Species	Floating Bags	Floating Cages	Hanging Baskets	Lantern Net Cages	Line Cultivation	Raft Culture
Pacific Oyster	X	X	X	X	X	X
Eastern Oyster	X	X	X	X	X	X
Kumamoto Oyster	X	X	X	X	X	X
Olympia Oyster	X	X	X	X	X	X
European Flat Oyster						
Suminoe Oyster						
Hard Clam						
Manila Clam						
Geoduck Clam						
Soft-Shell Clam						
Atlantic Surf Clam						
Sunray Venus Clam						
Littleneck Clam						
Butter Clam						
Mediterranean Mussel	X				X	X
Blue Mussel	X				X	X
Bay Mussel	X				X	X
Bay Scallop						
Atlantic Sea Scallop						
Purple Hinge Rock Scallop						
Pac. Weathervane Scallop				X		
Japanese Scallop				X		
Abalone			X			

Appendix B. Commercial U.S. Mariculture Cultivation Method, by Species

Species	**Manual Harvest**	**Mechanical Harvest**	**Planted Culch Manual Harvest**	**Planted Culch Mechanical Harvest**	**Direct Cultivation**	**Oyster Longlines**	**Stake**	**Rack and Bag**	**Support Cages**
Pacific Oyster			X	X	X	X	X	X	X
Eastern Oyster			X	X	X	X	X	X	X
Kumamoto Oyster			X	X	X		X	X	X
Olympia Oyster			X	X	X	X	X	X	X
European Flat Oyster									
Suminoe Oyster									
Hard Clam	X	X	X						
Manila Clam	X		X						
Geoduck Clam	X								
Soft-Shell Clam	X		X						
Atlantic Surf Clam	X								
Sunray Venus Clam	X	X	X						
Littleneck Clam									
Butter Clam	X								
Mediterranean Mussel			X						
Blue Mussel			X						
Bay Mussel			X						
Bay Scallop			X						
Atlantic Sea Scallop			X						
Purple Hinge Rock Scallop			X						
Pac. Weathervane Scallop									
Japanese Scallop									
Abalone									

Appendix C. Thresholds by Cultivation Method and Species

Gear Type	Tide Min (m)	Tide Max (m)	Current Min (m/s)	Current Max (m/s)	Depth Min (m)	Depth Max (m)
Covered In Bottom manual	0.13	-1.63	0.01	0.25	-0.03	-1.25
Covered In Bottom mechanical	0.13	-1.63	0.01	0.25	-0.03	-1.25
Floating Bags*	0.13	+	0.01	2.20	-0.75	+
Floating Cages*	0.13	+	0.01	2.20	-0.75	+
Hanging Basket*	-1.63	+	0.01	2.20	-5.00	+
Horizontal Longlines	-1.63	+	0.01	1.50	-5.00	+
In Bottom	0.13	-1.63	0.01	0.70	-0.25	-1.00
Lantern Nets Cages*	-1.63	+	0.01	1.00	-5.00	+
Line Cultivation	-1.63	+	0.01	1.20	-0.75	+
Planting Seeded Cultch manual	0.13	-1.63	0.01	1.00	-0.25	-1.25
Planting Seeded Cultch	-1.63	+	0.01	1.00	-0.25	+
Rack and Bag	0.13	-1.63	0.01	0.60	-0.75	-1.50
Raft Culture*	-1.63	+	0.01	0.25	-5.00	+
Seabed Cultivation	-1.63	+	0.01	1.52	-5.00	+
Stake	0.13	-1.63	0.01	0.25	-0.30	-1.50
Substrate Nets	-1.63	+	0.01	0.60	-2.00	+
Supported Cages	-1.63	+	0.01	0.60	-3.00	+

+ No maximum depth limit defined for gear type, the maximum depth of study area used.
* Cultivation method has promise for use in Alaska.

Appendix C. Thresholds by Cultivation Method and Species

Species	Scientific Name	Temp. (°C)	Salinity (ppt)	Current (m/s)	Turbidity (mg/L)	Dissolved Oxygen	pH
Pacific Oyster*	*Crassostrea gigas*	10 - 30	20 - 37	Moderate	< 250	Low (1 mg/L) for short periods	8-9
Olympia Oyster	*Ostrea lurida*	13 - 18	25 - 40	Moderate	-	Low (1 mg/L) for short periods	8-9
Manila Clam	*Venerupis philippinarium*	5 - 28	15 - 35	Moderate	< 23	Low (1 mg/L) for short periods	6.8-8.5
Geoduck Clam*	*Panopea Generosa*	8 - 19	26 - 34	Moderate	-	Low (1 mg/L) for short periods	6.8-8.5
Butter Clam	*Saxidomus gigantea*	3 - 23	20 - 35	Moderate	-	Low (1 mg/L) for short periods	6.8-8.5
Softshell Clam	*Mya arenaria*	3 - 23	5 - 30	Moderate	-	Low (1 mg/L) for short periods	6.8-8.5
Native Littleneck Clam*	*Leukoma staminea*	3 - 23	20 - 35	Moderate	-	Low (1 mg/L) for short periods	6.8-8.5
Horse Clam	*Tresus capax*	3 - 23	20 - 35	Moderate	-	Low (1 mg/L) for short periods	6.8-8.5
Cockles*	*Cardiidae spp.*	3 - 23	20 - 35	Moderate	-	Low (1 mg/L) for short periods	6.8-8.5
Blue Mussel*	*Mytilus edulis*	2 - 27	20 - 35	Slow-Moderate	< 20	Low (1 mg/L) for short periods	8-9
Mediterranean Mussel	*Mytilus galloprovincialis*	10 - 21	20 - 35	-	-	Low (1 mg/L) for short periods	8-9
Purple Hinged Rock Scallop*	*Crassadoma gigantea*	10 - 27	23 - 40	Moderate-Strong	-	Intolerant at low conditions	-
Pacific Weathervane Scallop*	*Patinopecten caurinus*	10 - 27	23 - 40	Moderate-Strong	-	Intolerant at low conditions	-
Abalone	*Haliotis spp.*	7 - 27	27 - 35	Moderate-Strong	-	Low (1 mg/L) for short periods	-

* Species has promise for mariculture cultivation in Alaska. Note only species native to Alaska, with the exception of Pacific oysters, can be cultured in Alaska.

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Appendix C. Thresholds by Cultivation Method and Species

Species	Scientific Name	Temp. (°C)	Salinity (ppt)	Current (m/s)	Turbidity (mg/L)	Dissolved Oxygen	pH
Sugar kelp*	*Saccharina latissima*	3 - 18	20 - 37	Low – Strong	-	-	7-9
Bull kelp*	*Nereocystis luetkeana*	5 - 17	20 - 40	Moderate – Strong	-	-	7-9
Ribbon kelp*	*Alaria marginata*	3 - 17	15 - 37	Moderate - Strong	-	-	7-9
Giant kelp*	*Macrocystis tenuifolia*	3 – 18	25 - 37	Moderate – Strong	-	-	7-9
Dragon kelp*	*Eularia fistulosa*	2 - 16	25 - 37	Moderate – Strong	-	-	7-9
Split kelp*	*Hedophyllum nigripes*	3 - 16	25 - 37	Moderate - Strong	-	-	7-9
Pacific dulse*	*Develaraea mollis*	4 – 15	10 – 35	Low – Moderate	-	-	7-9
Stiff red ribbon kelp	*Palmaria hecatensis*	1 – 15	10 - 33	Low – Moderate	-	-	7-9
Black seaweed*	*Pyropia abbottiea*	5 - 14	20 – 37	Moderate - Strong	-	-	7-9

* Species has promise for mariculture cultivation in Alaska. Note only species native to Alaska, with the exception of Pacific oysters, can be cultured in Alaska.