NOAA FISHERIES

Alaska Fisheries Science Center

AQUACULTURE STRATEGIC SCIENCE PLAN

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I. Introduction

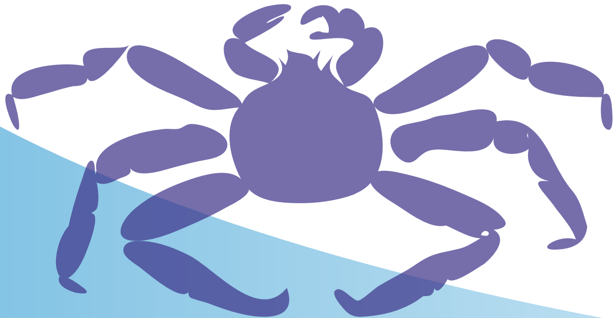
The cold and nutrient rich waterways of Alaska are ideally suited for the development of shellfish and algae aquaculture (also known as mariculture). While the industry is currently small (as of January 2022, approximately 82 permitted farms and 24 farms with permits pending; current value is approximately $1.5 million), the Governor's Mariculture Task Force set the goal of developing a $100 million per year aquaculture industry in Alaska State waters in 20 years through workforce development, investment in or adaptation of seafood processing, hatchery, and harvesting infrastructure, research and development of current and new aquaculture species and products, and regulatory changes (Mariculture Task Force 2021). With such rapid growth comes the potential for impacts (both positive and negative) to wild populations, other fisheries, subsistence intertidal and subtidal harvest, marine mammals, and other uses of the coastal zone. In order to accomplish the triple bottom line of sustainable aquaculture - environmental, economic, and social sustainability – communication and collaboration across diverse partnerships will be critical. These partnerships include: federal and state agencies, non-governmental and nonprofit organizations, Alaska Native communities, corporations, and governments, universities, growers, hatcheries, and any other groups involved in the use or management of the coastal zone.

At the time of writing, aquaculture in Alaska is only taking place in state waters with expansion to federal waters unlikely in the next five years.

At the time of writing, aquaculture in Alaska is only taking place in state waters with expansion to federal waters unlikely in the next five years. Finfish farming is prohibited by law in state waters, though finfish hatcheries are permitted. The potential for interactions between farms and protected species, Essential Fish Habitat, other fisheries (e.g. salmon, halibut, crab, geoduck, sea cucumber), and the potential for future expansion into federal waters, all warrant involvement from the National Marine Fisheries Service. The main regions of aquaculture development in Alaska currently are Southeast and Southcentral (Prince William Sound, Kenai Peninsula, and Kodiak).

- Southeast AK 43 operations (52.44%)
- Southcentral AK 37 operations (45.12%)
- Western AK 2 operations (2.44%)

The purpose of this document is to guide and promote the aquaculture research and actions of the Alaska Fisheries Science Center (AFSC) through the Aquaculture Working Group over the next five years. This plan specifically includes shellfish (Pacific oysters, pinto abalone, king crab), other invertebrates (sea cucumber), and algae (kelp and red algae). It is intended to guide the actions of AFSC researchers and inform strategic directions of the AFSC Board of Directors and other leadership, and facilitate coordination with other National Marine Fisheries Service branches, such as the Alaska Regional Office (AKRO) and other regional offices, the Office of Aquaculture, and other regional science centers, and other NOAA branches, such as the National Centers for Coastal Ocean Science (NCCOS), the National Ocean Service (NOS), the Office of Oceanic & Atmospheric Research (OAR), and the various Sea Grant programs. The plan was developed through conversations within the AFSC Aquaculture Working Group, collaborations with university, government, industry, and community partners, and other guiding documents and strategic plans, including the AKRO-AFSC Alaska Aquaculture Action Plan.



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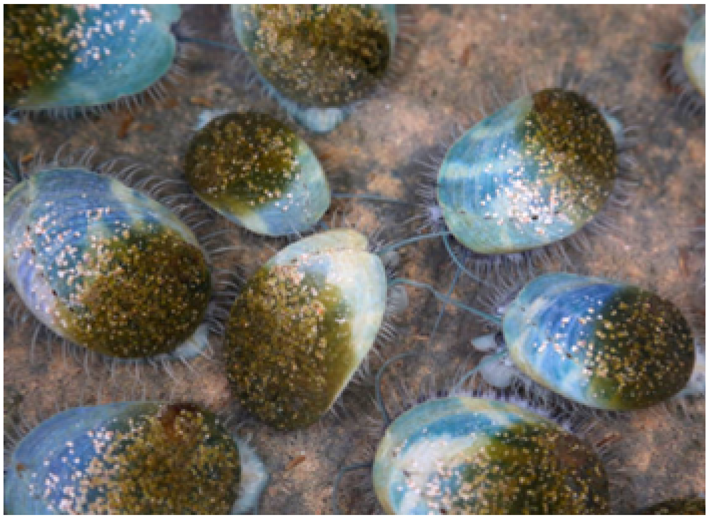

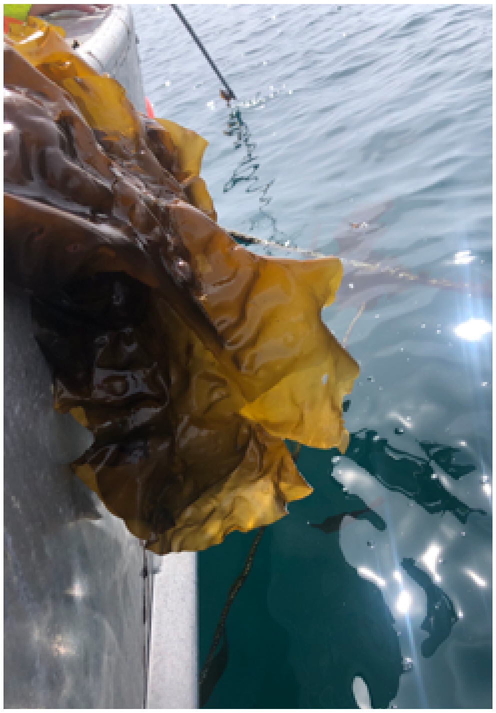

II. Definitions

For the purposes of this document, frequently-used terms are defined as follows:

Aquaculture, Mariculture, or Aquatic Farming: the culturing of finfish, shellfish, invertebrate, and aquatic plant organisms in captivity or under positive control in the near shore environment. In Alaska, commercial finfish aquaculture is prohibited, though finfish hatcheries are permitted (from Alaska Department of Fish and Game, or ADF&G).

Hatchery: facilities to spawn and rear early life stages of species before transfer to an aquatic farm or the wild for population enhancement or restoration.

Enhancement: release of hatchery-reared juvenile or adult organisms to support harvest while also reducing pressure on wild populations.

Restoration: release of hatchery-reared juvenile or adult organisms to increase numbers of populations at low levels.

Grow-out: the stage at which juveniles are grown to market or release size.

Kelp: Species of brown macroalgae in the order Laminariales. Kelp species currently farmed in Alaska include sugar kelp (*Saccharina latissim*a), ribbon or winged kelp (*Alaria marginata*), and bull kelp (*Nereocystis luetkeana*). There is interest in cultivation of non-kelp macroalgae such as black seaweed or nori (*Pyropia abbottiae*) and red ribbon algae or Pacific dulse (*Devaleraea mollis*, previously *Palmaria mollis*).

Multi-trophic aquaculture: co-culturing of multiple species such that one or more species cultivated may benefit from the others' presence.

III. Federal role in aquaculture research in Alaska

A. Laws and mandates

A subset of the laws and mandates that govern actions of the AFSC in aquaculture development and research.

Magnuson-Stevens Fisheries Conservation and Management Act is the primary law that governs marine fisheries management in U.S. federal waters, with the goals of preventing overfishing, rebuilding overfished stocks, increasing long-term economic and social benefits, and ensuring a safe and sustainable supply of seafood. These goals are accomplished in part through ecosystem-based management and the establishment of essential fish habitat and habitat conservation areas. Under this act, federal agencies must consult with NOAA Fisheries regarding any action authorized, funded, or undertaken, or proposed to be authorized, funded, or undertaken that may adversely affect Essential Fish Habitat (EFH).

National Aquaculture Act establishes aquaculture as a national policy and is intended to promote and support the development of aquaculture in the US while preserving ocean sustainability.

Executive Order Promoting American Seafood Competitiveness and Economic Growth (EO 13921) updates U.S. aquaculture policy, including removing unnecessary regulatory barriers, increasing regulatory transparency and strategic planning for aquaculture development, and maintaining a healthy aquatic environment. This EO also mandates the establishment of Aquaculture Opportunity Areas (AOAs), small defined geographic areas that have been evaluated to determine potential suitability for commercial aquaculture. AOAs are the most comprehensive marine spatial planning exercise undertaken by the U.S. federal government to date.

Endangered Species Act (ESA). Under section 7(a)(2) of the ESA, Federal agencies must consult with NOAA Fisheries on activities that may affect a listed species, which includes all marine and anadromous species listed under the ESA, except for sea otter, walrus, and polar bear which are under the purview of the US Fish and Wildlife Service. These interagency, or section 7, consultations are designed to assist Federal agencies in fulfilling their duty to ensure any action they authorize, fund, or carry out is not likely to jeopardize the continued existence of a listed species or result in the destruction or adverse modification of designated critical habitat. In fulfilling these requirements, each agency must use the best scientific and commercial data available. ESA-listed species under NOAA Fisheries jurisdiction in Alaska include: marine mammals, reptiles, and fish.

Marine Mammal Protection Act (MMPA) is intended to prevent adverse impacts to marine mammal populations, including deaths from entanglement in aquatic gear. NOAA Fisheries is responsible for the management of whales, dolphins, porpoises, seals, and sea lions. Walrus, sea otters and polar bears are Alaska species managed by the U.S. Fish and Wildlife Service (FWS).

National Environmental Policy Act (NEPA) requires federal agencies to consider environmental impacts of their major actions and ensure compliance with the above laws, among other laws and regulations. The decision maker must use the best available scientific information and analysis to present the environmental effects of the proposed action and alternative(s) in comparative form, providing a clear basis for choice among the options.

B. Partnerships

AFSC actions on aquaculture research are also guided by strategic partnerships with entities within and outside Alaska. In addition to the partnerships listed below, the AFSC Aquaculture Working Group will prioritize future engagement with the international community. This can be achieved through continued engagement with international partners who already have bilateral agreements with NOAA Fisheries, including researchers at the Fisheries and Oceans Canada, especially researchers in British Columbia, and intergovernmental research organizations such as the International Council for the Exploration of the Sea (ICES) and the North Pacific Marine Science Organization (PICES).

NOAA AFSC Aquaculture Working Group. This working group is composed of 14 researchers from various line offices within AFSC who are interested in and/or engaged with aquaculture research. The group meets every other month to discuss aquaculture research activities, plan future projects, and prioritize research directions within AFSC.

NOAA Alaska Regional Office (AKRO). The AFSC aquaculture researchers maintain regular communications with the AKRO Regional Aquaculture Coordinator to aid in coordination of research priorities and funding opportunities, and contribute to science for management. In addition, AFSC Aquaculture Lead Researcher participates in the monthly Alaska Aquaculture Team meetings held by the Regional Office. The shared mission for socially and ecologically sustainable aquaculture development is also reflected in the NOAA Fisheries Alaska Geographic Strategic Plan for FY 2020-2023 and the Joint Alaska Aquaculture Action Plan.

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NOAA Office of Aquaculture (OAQ). The AFSC Aquaculture Lead Researcher also communicates regularly with OAQ leadership and researchers to align research priorities in Alaska with national priorities in aquaculture research, as outlined in the Marine Aquaculture Strategic Plan for FY 2016-2020, and made actionable through the Joint Alaska Aquaculture Action Plan. OAQ also provides financial support for aquaculture research at the AFSC through the Internal Call for Aquaculture Funds (ICAF) program and other sources. OAQ and the AKRO Regional Aquaculture Coordinator also serve as bridges between AFSC aquaculture research and regional aquaculture programs throughout NMFS.

Alaska Mariculture Alliance (AMA). A non-profit representing major stakeholders from the Alaska aquaculture industry. This group was formed after the conclusion of the Mariculture Task Force, a Governor-appointed task force that brought together industry, research, and coastal communities to guide aquaculture development in Alaska. The Director of the AFSC serves as an ex-officio member of the AMA.

Aquaculture research necessarily intersects with many state and federal agencies for permitting, environmental interactions, and human health and safety.

Mariculture Research and Training Center (MRTC). The need for a MRTC was identified in the Alaska Mariculture Development Plan. The MRTC is being led by Alaska Sea Grant and operates in connection with the Alaska Mariculture Alliance (AMA). The MRTC was established to operate as the research arm of the AMA, and focus on coordinating research, outreach, and grant writing among major stakeholders to enhance the pace of research and development in Alaska. The Aquaculture Lead Researcher from AFSC serves on the board of the MRTC.

Cooperative Research and Development Agreement with Blue Evolution. Blue Evolution is a private company that grows various kelp species in southcentral Alaska and processes and markets kelp and other macroalgae for human consumption. The company maintains a CRADA with the NOAA Fisheries Kodiak Laboratory to develop kelp hatchery methods in Alaska. This relationship has resulted in an efficient kelp hatchery that supplies seed to farms throughout southcentral Alaska. Future research topics are being explored within this CRADA, including an improved understanding of kelp interactions with and alterations to the carbonate system.

Alaska Shellfish Growers Association (ASGA). This group represents primarily oyster farmers in Alaska, as well as a growing number of kelp farmers. The AFSC Aquaculture Lead Researcher participates in the annual ASGA conference and communicates regularly with ASGA members and leadership to collaborate with industry on priority shellfish research goals.

Alaska Sea Grant: Alaska Sea Grant is headquartered at the University of Alaska Fairbanks and funded by the NOAA National Sea Grant Program. This entity participates in marine research, outreach, and education, including on aquaculture topics. AFSC aquaculture researchers regularly engage with Alaska Sea Grant through grant proposals, the AMA and MRTC, and other research and training opportunities.

Other Alaska state and federal agencies: Aquaculture research necessarily intersects with many state and federal agencies for permitting, environmental interactions, and human health and safety. AFSC researchers are or will be engaged with Alaska state agencies, including the Department of Environmental Conservation, the Department of Fish and Game, and the Department of Natural Resources. Engagement will also include federal agencies, such as the Department of Energy, the Army Corps of Engineers, the U.S. Fish and Wildlife Service, the U.S. Coast Guard, the U.S. Forest Service, and the U.S. Department of Agriculture.

IV. Goals, challenges and opportunities

This section specifies priority goals in AFSC aquaculture research, as well as some of the major challenges facing the sustainable growth of the aquaculture industry and the opportunities for AFSC to address these challenges.

GOAL: Promote sustainable industry growth through monitoring and improved understanding of ecosystem interactions

1. Challenges

In-water aquaculture in Alaska is embedded in the nearshore environment. With this proximity comes the potential for interactions with and impacts to the species and habitats that occupy this zone.

The establishment of aquaculture infrastructure entails the creation of mid-water structures consisting of floats, anchors, cables, cages, and lines which can reduce available light to the benthos, and the introduction of cultivated species and their metabolic processes. The degree to which these additions change habitat depends on the site. For example, in soft-bottomed sites, the introduction of three dimensional structure represents a novel habitat. Likewise, aquatic farms create floating mid-water structures, which are often a novel habitat for a given area. This novel structure may serve as an attractant or deterrent to different species and result in species assemblages that may augment surrounding wild populations or fundamentally differ from that which was present before installation (Theuerkauf et al. 2021).

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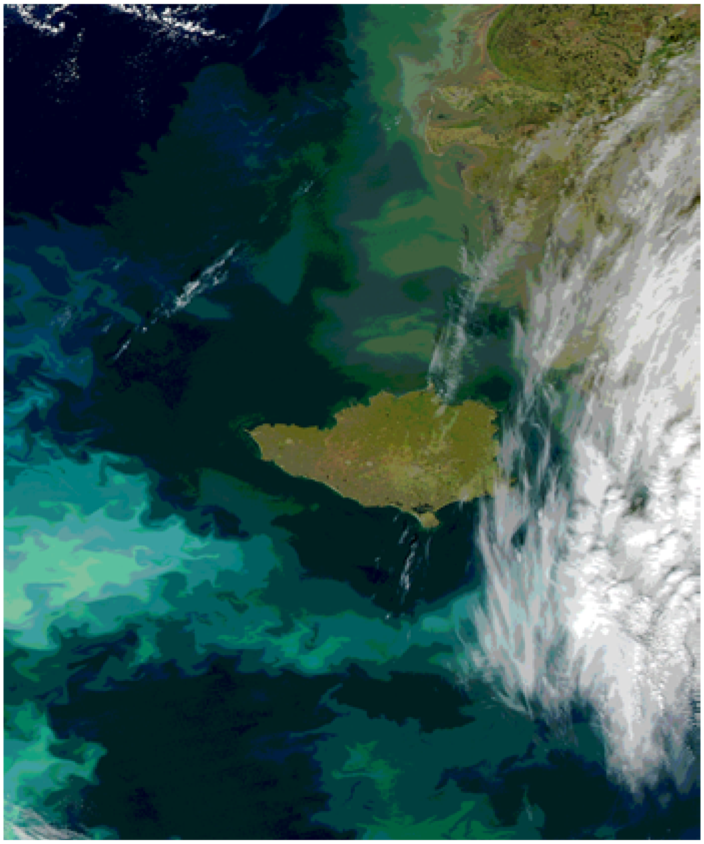
Likewise, the introduction of shellfish or algae can alter the carbon and nitrogen cycling in an area, with the extent of impact dependent on the size of the farm and the local hydrographics (Forrest et al. 2009; Xiao et al. 2021). Shellfish waste consists of dissolved organic nitrogen, and sloughed algal tissue is composed of particulate and dissolved organic carbon; both of which can readily enter benthic and pelagic food chains. Algal photosynthesis involves the uptake of CO_2 and release of O_2 which can change diel carbon and oxygen cycling (Murie and Bourdeau 2020), and algae absorb nitrogen, phosphorus, and other nutrients which can alter local nutrient availability (Racine et al. 2021). Filter feeders, such as oysters, consume phytoplankton and, in certain conditions of high oyster density and/or low phytoplankton abundance, may reduce phytoplankton densities in a given bay with potential consequences for wild filter feeding organisms. However, the large scale of the phytoplankton blooms in coastal Alaska makes it highly unlikely that oyster farms would result in significant reductions in phytoplankton biomass. Depending on the size of the farm and the local oceanographic context, these water column changes could impact biotic communities, higher pH levels due to daytime photosynthesis, and/or higher levels of biologically available nitrogen and carbon from oyster and kelp waste products (Forrest et al. 2009).

Rapid detection and eradication of nonnative species or disease outbreaks associated with aquaculture in Alaska will be critical.

Aquaculture also comes with biosecurity risks, such as the potential for introduction of invasive species and disease and genetic alterations to wild stock, as well as increased human exposure to environmental toxins such as domoic acid from the consumption of oysters exposed to harmful algal blooms. This risk of invasive species introductions is lower for the farming of kelp or other species that are sourced locally. In regions outside of Alaska, the movement of Pacific oysters for aquaculture has resulted in the introduction and spread of numerous invasive species, including the algae *Gracilaria* spp., the bryozoan *Smittoidea prolifica*, and various species of predatory oyster drill. To date, there are no known established populations of these species in Alaska. Where these species have established in other regions, they have outcompeted native macrophytes, fouled human and biotic structures, and heavily predated upon native shellfish species, respectively (Hu and Lopez-Bautista 2014; Cheng et al. 2021). Likewise, the dense farming of monocultures of locally sourced species, such as kelp, can allow disease to propagate and spill out into wild beds. Rapid detection and eradication of nonnative species or disease outbreaks associated with aquaculture in Alaska will be critical. Warming SST may result in successful Pacific oyster recruitment outside of aquatic farms (current temperatures act as a barrier to reproduction in this species) if non-sterile seed stock is planted, which could result in competition with native shellfish species. Current regulations in Alaska require that spores for macroalgae cultivation are sourced from 50 parent plants within 50 km of a farm in order to reduce any



alterations of population genetic structure of wild beds. Harmful algal blooms (HABs) and *Vibrio* bacteria are an increasingly severe threat to shellfish industries due to the toxins that can accumulate in farmed shellfish, resulting in severe illness such as paralytic or amnesiatic shellfish poisoning or severe gastronomic upset if consumed. Farmers currently have few tools to be able to monitor HAB events or *Vibrio* at their farms, resulting in high costs for testing and temporary farm closures if samples are found to have unsafe levels of toxins. An SST modeling tool recently developed by NCCOS is intended to aid farmers in preventing *Vibrio* growth.

The addition of lines and midwater structure presents the potential for interactions between marine mammals and aquaculture infrastructure. There have been no records of interactions with aquaculture gear resulting in harm to a marine mammal in Alaska to date. However, concern exists that aquaculture could serve as either an attractant, in which a marine mammal is attracted to a farm therefore increasing the risk of potential entanglement, or deterrent, in which the presence of a farm deters marine mammals from an area with possible consequences for feeding, rest, or reproduction.

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2. Research opportunities

Genetic tools for biosecurity monitoring and ecosystem interactions: The AFSC Genetics program has the expertise and infrastructure to apply genetics tools to aquaculture research needs. These tools include the use of environmental DNA (eDNA), a powerful tool for monitoring biosecurity threats and the consequences of aquaculture on surrounding ecosystems. Targeted sampling of eDNA can inform the potential benefits and consequences of aquaculture by monitoring community composition inside and outside of farm sites, as well as for rapid monitoring of invasive species and other emerging threats. The Genetics program can also lead efforts to improve understanding of population genetic structure and potential genetic risks to neighboring wild populations, as well as provide concrete data to help the state construct effective regulations. Further, genetics data will be critical to evaluate appropriate populations to supply broodstock for stock enhancement activities in order to maintain the genetic integrity of enhanced populations.

Risk analyses: Expertise within the Resource Ecology and Fisheries Management (REFM) division could be used to conduct invasive species forecasting and risk analyses given aquaculture expansions and climate change. This work could be done in collaboration with AKRO's Habitat Conservation Division and Invasive Species Lead. Results could be used to implement measures that mitigate risk. There are also potentials here for engagement and collaboration with researchers in comparable regions with longer histories of high-volume aquaculture, such as British Columbia and Washington.

Harmful algal blooms: Knowledge and infrastructure at AFSC for phytoplankton identification and nearshore monitoring of environmental parameters will be major assets for improving understanding of interactions between HAB events and toxicity in farmed bivalves. Coordination and partnership with the Alaska Harmful Algal Bloom network, NCCOS, the Alaska Department of Environmental Conservation Shellfish Program, the Alaska Shellfish Growers Association, and Alaska oyster farms will be necessary. Coordination with ongoing efforts at the Northwest Fisheries Science Center in partnership with the National Ocean Service and the National Environmental Satellite Data and Information Service (NESDIS) will aid efforts in Alaska.

Understanding how aquaculture impacts marine mammals and essential fish habitat in Alaska will improve siting and regulatory decisions.

Interactions with protected resources: Understanding how aquaculture impacts marine mammals and essential fish habitat in Alaska will improve siting and regulatory decisions. The Marine Mammal Laboratory (MML) and other AFSC divisions are well suited to addressing this challenge, both with existing surveys and with the possibility of using similar or novel survey and experimental methods in regions with high volumes of aquaculture. AFSC researchers are currently collaborating with AKRO to investigate low-impact acoustic methods to deter herring from spawning on aquaculture infrastructure. As part of the Regional Action Plan for the Gulf of Alaska, MML in coordination with AKRO, could capitalize on both existing surveys and design focused aerial effort to gather more detailed time series of abundance and distribution of pinnipeds and cetaceans near proposed farming areas; particularly focusing efforts on conducting surveys during times of the year when pinnipeds are hauling out to have pups. Better resolution data will enable more detailed analyses to increase power of detected population impacts due to farming construction and ongoing activity.

Ecosystem monitoring: Ecosystem impacts (positive, negative, or neutral) are likely to vary across spatial scales. As mentioned above, the AFSC Genetics program has the necessary infrastructure and expertise to lead eDNA studies which can estimate community composition of invertebrates, mammals, birds, and other non-fisheries fin fish species. The EMA group houses extensive knowledge of plankton species which could be collected within and around farm sites using plankton tows. This would improve our understanding of species recruitment and use of farms in early life stages. Finally, the ABL and Kodiak dive programs are teams of well trained divers from various AFSC divisions who have the necessary training to survey macroinvertebrates and benthic and pelagic fish in and around farm sites and conduct pre and post-enhancement counts to evaluate the success and effects of enhancement activities.

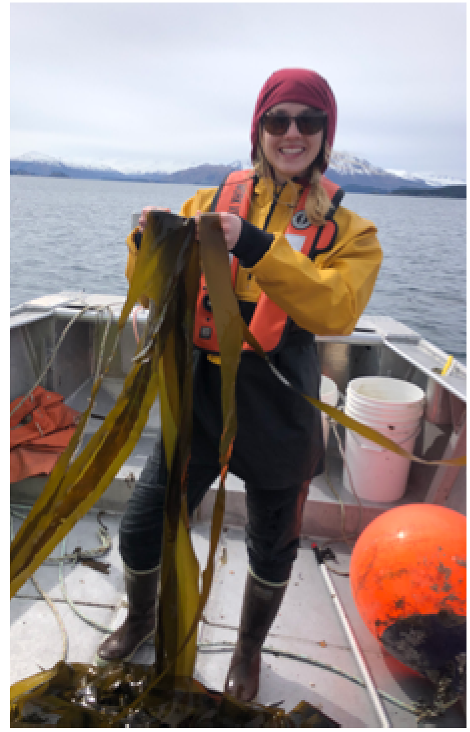
Biogeochemical changes: Farmed species may change the biogeochemical environment of farms, with consequences for other species. RECA, EMA, and the Newport and Kodiak Labs all have infrastructure for water chemistry analyses, including carbon system parameters (pH, pCO_2, aragonite and calcite saturation states) and nutrient concentrations.

GOAL: Promote economically and socially sustainable and equitable growth

1. Challenges

Various challenges exist in Alaska that could hamper progress towards the NOAA Blue Economy Strategic Plan, the Alaska Geographic Strategic Plan, and the Executive Order on Promoting American Seafood Competitiveness and Economic Growth (EO 13921) goals of amplifying the economic value of aquaculture. These include ensuring there is equitable access to the industry and high social license for aquaculture, increasing access to markets, product development (especially for kelp products), increasing kelp and shellfish hatchery capacity, reducing regulatory barriers while ensuring ecological sustainability, and exploring methods to increase the economic efficiency of aquaculture operations, including farming methods, selective breeding, integrated multi-trophic aquaculture, and new species.

Kelp has many potential uses, as direct food for human or animal consumption, fertilizer, source of alginate and other compounds for food additives, pharmaceuticals, and personal hygiene products, and potential for biofuel.



2. Research opportunities

Aquaculture Opportunity Areas (AOAs): AOAs are among the most comprehensive regional marine spatial analyses ever conducted for US federal waters and are currently focused on Southern California and the Gulf of Mexico. AOAs do not exist in Alaska, but may be pursued in the future. The end result of the AOA process is the designation of specific areas best suited to aquaculture development. In the process, maps are created that indicate which regions have both low user conflict, including human uses of the marine zone and the presence of protected resources, and have attributes deemed positive for aquaculture in the region, such as proximity to ports or processing facilities. This effort is led by OAQ, the Regional Office where AOAs are located, and the NOAA National Centers for Coastal Ocean Science (NCCOS). Should Alaska be chosen as a future AOA location, AFSC programs will work with AKRO and NCCOS to determine which data layers should be included in the spatial analyses. Expertise within the AFSC Economics and Social Sciences Research Program (ESSRP) can contribute to AOA siting through research on socio-economic impacts of various aquaculture scenarios, including variations in farm (or AOA) size or species grown, and proximity to ports, ADEC testing facilities, processing facilities, and other critical infrastructure. The Alaska Fisheries Development Foundation, an Alaska-based nonprofit dedicated to developing the Alaska seafood industry, would also be an important partner in modeling efforts. This is a stakeholder driven process, and if located in state waters would be driven by the needs of the state and other stakeholders.

Equitable access to the industry and social licensing: Socially sustainable growth and acceptance of aquaculture in Alaska entails that access to the industry is equitable, or that the demographics of people in the aquaculture industry match the demographics of the state. AFSC can contribute to diversifying the perspectives represented in research by collaborating with industry, coastal communities, Alaska Native entities, conservation organizations, fisheries, and other groups who are interested in or impacted by aquaculture development. Listening sessions with these groups is a good first step in understanding concerns and directing research priorities based on community needs. The newly created Tribal Research

AFSC aquaculture researchers can collaborate on or lead research and development into new species and methods to enhance yield of current species.

Coordinator position within AFSC and the AFSC communications team would both be strong partners in these efforts, as well as social scientists in ESSR, and the AKRO tribal engagement team and co-management leads.

Product development. A major challenge in the expansion of kelp aquaculture is finding markets for the product. Kelp has many potential uses, as direct food for human or animal consumption, fertilizer, source of alginate and other compounds for food additives, pharmaceuticals, and personal hygiene products, and potential for biofuel. Collaboration between AFSC and the University of Alaska Fairbanks/Sea Grant Kodiak Seafood and Marine Science Center could investigate new products derived from kelp, with Kodiak kelp farms supplying multiple kelp species. Likewise, research into alternative finfish and other aquaculture feeds conducted out of the NWFSC could include kelp and other macroalgae. The Alaska Fisheries Development Fund is also investigating kelp product development and could be a good partner in these efforts.

Reducing regulatory barriers. There are many regulatory requirements to install and operate an aquatic farm in the US, including in Alaska. Executive Order 13921 mandated that agencies reduce regulatory hurdles. AFSC will contribute to these efforts by supporting research for Aquaculture Opportunity Area (AOA) siting tools, should Alaska be chosen as a future AOA site. Research on population genetic structure, as outlined above, will also contribute to local regulations regarding the harvesting of seed for macroalgae aquaculture. Also research on marine mammal interactions and habitat impacts, as outlined above, will assist with ESA, NEPA EFH, and MMPA regulatory requirements. AFSC researchers will maintain close working relationships with other experts within NOAA and regulatory agencies at the state and federal level, including the Army Corps of Engineers, AKRO, ADF&G, and the Alaska Department of Environmental Conservation.

Enhancing hatchery capacity. Alaska oyster farms currently source seed from hatcheries in the Pacific Northwest and Hawaii, and these strains are usually optimized for growth in the Pacific Northwest. In years when seed availability is limited, Alaskan farms often have trouble procuring it. Some hatchery infrastructure exists, such as the Alutiiq Pride Shellfish Hatchery in Seward and OceansAlaska in Ketchikan, however neither are producing Pacific oyster seed at the time of writing. The AFSC can contribute to this work by leading or collaborating on research and development on oyster strain selection and hatchery protocols. Existing Alaska hatcheries and oyster growers would be key partners in these efforts. To overcome the regulation that prohibits laboratories from holding live pacific oysters, TSMRI could apply for hatchery permits. Partnerships with USDA ARS, the Molluscan Breeding Program and Oregon State University, and other branches of NOAA Fisheries could be additional partners on these efforts.

Increase economic efficiency. Production efficiency on farms can be increased by introducing endemic species that are not currently cultured in Alaska and which may have higher growth rates, investigating growing methods and strain selection for current species to enhance yield, and by growing multiple species at once in an integrated multitrophic system. Expertise and infrastructure in RECA is well suited to investigating trophic interactions and energetics transfer in polyculture settings, while the Genetics program can assist in strain selection while maintaining adequate genetic diversity. AFSC aquaculture researchers can collaborate on or lead research and development into new species and methods to enhance yield of current species. Dive teams can help design and conduct manipulative experiments to evaluate the effectiveness of grow-out or release strategies.

GOAL: enhance the resiliency of Alaska aquaculture to global change

1. Challenges

Global change, including climate change and other anthropogenic influences, will likely drive significant changes to all ecological processes, including the cultivation of species in the ocean through aquaculture. Specific threats include increasingly common and severe marine heatwaves, gradual increases in sea surface temperature (SST), ocean acidification (OA), changes in precipitation patterns, and shifting species ranges.

Short- and long-term changes in SST can dramatically impact aquaculture. The major marine heatwave of 2014/2015 had significant bottom-up impacts on Gulf of Alaska foodwebs (Suryan et al. 2021) and contributed to extirpations of wild kelp in other regions, such as Northern California (Rogers-Bennett and Catton 2019) and parts of Vancouver Island, British Columbia (Starko et al. 2019). A record-breaking heatwave in the summer of 2021 led to widespread mortality of farmed and wild shellfish across the coast of Washington and British Columbia. While Alaska kelp populations have remained relatively stable (Evenson and Hollarsmith, unpublished data), marine heatwaves present a major future threat to the continued availability of spores that are currently necessary for kelp hatcheries. Heatwaves and rising SST also threaten the grow-out phase of cultivated species, as warmer air and water temperatures can contribute to the rapid and premature degradation of algal tissue (Simonson et al. 2015), disease, mortality, and altered spawning behavior in oysters (Delisle et al. 2018; Hollarsmith et al. 2020a; Ubertini et al. 2017), and increased frequency and duration of harmful algal blooms (Harley et al. 2020), among other effects. Changes in SST across different spatial and temporal scales can also alter species distributions. Shifts in the ranges of protected or pest species have a great potential to impact aquaculture operations in the near future.

Alaska waters already have high seasonal and spatial variability in pH, with lows driven by freshwater input, very low SST, advection of offshore water onto the coastal shelf, and phytoplankton blooms (Hauri et al. 2021; Miller and Kelley 2021). Ocean acidification from anthropogenic carbon dioxide will lead to further decreases in pH and aragonite and calcite saturation states, posing a special threat to shellfish (both cultured and wild). Decreasing pH threatens the development of oyster, abalone, and king crab hatchery infrastructure in the near-term and the growth and survival of grow-out stages of oysters and enhanced king crab populations in the long-term (Barton et al. 2015; Long et al. 2013). Ocean acidification is unlikely to directly affect macroalgae hatchery or grow-out processes (Hollarsmith et al. 2020b), though macroalgae culture could act as an OA buffer at the local scale (Xiao et al. 2021).

Aquaculture in Alaska occurs in areas that experience high annual precipitation levels, and siting aquatic farms depends on limited input of terrestrial contaminants and salinity levels that are high enough to ensure the survival of cultivated species. As climate change alters precipitation patterns, including more intense rainfall events and transitions from snow to rain, the characteristics of current and future aquaculture sites may change (Bennett and Walsh 2015).

2. Research opportunities

The challenges of climate change present multiple opportunities for AFSC engagement and leadership based on current research expertise and infrastructure within the Center. Highlighted here are some opportunities for AFSC to lead research that addresses the challenges of climate change.

OA refugia: There is strong interest from industry and coastal communities in the potential for kelp farms to provide local refugia to OA, though the biologically relevant impacts of kelp photosynthesis and respiration on pH levels is likely highly context-dependent. Expertise within the AFSC on oceanography, ocean chemistry, fish physiology, and essential fish habitat could meaningfully contribute to improved understanding of this phenomenon through in situ water column monitoring in and around kelp farms, laboratory studies, and modeling. Researchers from the Alaska Ocean Observing System, University of Alaska, and the Pacific Marine Environmental Laboratories will be important collaborators in this work.

Carbon sequestration: The Department of Energy is interested in carbon dioxide removal strategies, including cultivating macroalgae for food or to intentionally sink the tissue, with sequestration potentially occurring throughout the growing process. The inter-Line Office NOAA marine carbon dioxide removal (mCDR) taskforce is leading the communication with other federal agencies to coordinate this research, which will include the NOAA Office of Aquaculture and AFSC, among other NOAA branches.

Genetic adaptation: The AFSC Genetics group is well poised to lead research efforts on adaptive genetic diversity for traits that may be affected by climate change and to predict populations most susceptible to climate change, or select for resistant strains in cultivated species, as permitted by regulations. The Alaska Department of Fish and Game will be an important regulatory partner in this work.

Physiological thresholds: Understanding the physiological tolerance of cultivated species to extreme temperature, pH, and salinity events is critical for site suitability, strain selection, and cultivation methods. The in-house expertise and lab infrastructure of the RECA Program encompasses habitat quality, trophic dynamics and organism nutritional condition that can contribute to this. Efforts should be made to coordinate and collaborate with researchers who study the same species in different parts of their range to better understand local differences in tolerance.

Water quality: Nearshore water quality, a critical piece of information for aquatic farms and hatcheries, may change with climate change. The EMA and REFM groups have the expertise to monitor changing water quality and use modeling approaches to project future changes based on climate change scenarios. For example, existing and future developments of ROMs and MOM6 oceanographic models in the GOA will also advance our ability to characterize and predict water quality conditions. The outputs of these oceanographic models can then be used to explain past trends and predict future ecosystem dynamics through ecosystem models in development under REFM's GOA-CLIM project (e.g., Atlantis and Ecopath with Ecosim). Additionally, there are opportunities to collaborate with the Alaska Department of Environmental Conservation, the Alaska Ocean Observing System, and the National Centers for Coastal Ocean Science (NCCOS). NCCOS is currently developing SST models for Alaska to help provide early warning to farmers on potential *Vibrio* growth. There are also collaboration opportunities with the Environmental Protection Agency and Alaska Native and other coastal communities. RECA, EMA, and the Newport and Kodiak Labs all have infrastructure for water chemistry analyses, including carbon system parameters (pH, pCO_2, aragonite and calcite saturation states) and nutrient concentrations.

Nearshore water quality, a critical piece of information for aquatic farms and hatcheries, may change with climate change.

Disease: Changing ocean conditions will likely contribute to introductions and outbreaks of diseases currently observed in lower latitudes but not yet found in Alaska, such as the oyster herpes virus (OSHV-1). While AFSC does not currently have in-house disease expertise, collaboration with other federal agencies and NMFS science centers could bring important research perspectives to Alaska. Within NMFS, the Northwest and Northeast Centers have disease experts on staff.

V. Priority goals and strategies

This section presents an overview of priority goals and strategies to achieve those goals for FY22 to FY27.

1. **Increase infrastructure and personnel capacity for AFSC aquaculture research**
   a. Build productive partnerships with personnel at other NMFS science centers, NOAA line offices, and state and federal agencies to bring outside expertise to Alaska aquaculture research and bring AFSC-based expertise to the rest of NOAA.
   b. Recruit participation from qualified students, interns, and fellows through the use of existing NOAA and Sea Grant programs, and university partnerships.
   c. Increase FTE time dedicated to aquaculture research through yearly Activity Plans and Performance Plans.
   d. Build materials and infrastructure capacity through budget requests in Activity Plans, internal grants (such as the Internal Call for Aquaculture Funding), and external grants.
   e. Build and maintain collaborations with AKRO, industry, academia, and coastal communities, including Alaska Native tribes.
   f. Engage with the international aquaculture research community.

2. **Promote sustainable industry growth through monitoring and improved understanding of ecosystem interactions**
   a. Develop strategies to minimize negative ecosystem interactions, such as herring spawning on kelp aquaculture infrastructure (ICAF funded, completed 2022).
   b. Monitor habitat use of aquaculture infrastructure by important fisheries species, including early life stages (applied for EVOS funded, begins 2022).
   c. Monitor and mitigate interactions between marine mammals and aquaculture infrastructure.
   d. Characterize relationships between environmental parameters (temperature, nutrients, salinity), harmful algal blooms, *Vibrios*, and oyster toxicity levels to develop monitoring and mitigation strategies for farmers (ICAF funded).
   e. Improve understanding of the population genetic structure of kelp species under cultivation, and assess potential genetic risks to neighboring wild populations (ICAF funded, ongoing).
   f. Evaluate genetic population structure of king crabs to inform management decisions on which populations could be used to enhance Kodiak red king crab and Pribilof blue king crab stocks, and collaborate with industry partners to conduct experimental outstocking to determine ecological and economic feasibility.

3. **Promote economically and socially sustainable growth**
   a. Support the development of AOAs in Alaska through collaboration and coordination with OAQ, AKRO, NCCOS, and Alaska state agencies.
   b. Conduct scenario analyses on aquaculture development in Alaska.
   c. Increase the portfolio of species grown in Alaska, with a focus on endemic species and multitrophic aquaculture.
   d. Build oyster hatchery production in Alaska through strategic partnerships and selective breeding of Alaska optimized strains (EVOS funded).

4. Enhance the resiliency of Alaska aquaculture to global change

- **a.** Investigate carbon and nutrient cycling within farms to understand potential for ocean acidification mitigation and multitrophic aquaculture (EVOS funded).
- **b.** Model climate envelopes of farmed species and use projections to assess how envelopes may shift with climate change; identify regions that are projected to be most suitable to cultivated species at present and within the next 50 years.
- **c.** Build and participate in collaborations to assess the carbon sequestration potential of macroalgae (ongoing through the Marine Carbon Dioxide Removal Task Force).
- **d.** Encourage siting remote sensing instruments near existing aquaculture farms and support software development for forecasting biotoxins and *vibrios*, to leverage existing efforts supported by NCCOS, AHAB, and ADEC.

5. Outreach and education

- **a.** Partner with educators to incorporate aquaculture education into school curriculums, including bringing students to NOAA field stations (such as Little Port Walter).
- **b.** Present at scientific conferences and to internal NOAA audiences.
- **c.** Publish findings in reports, white papers, webstories, and peer reviewed publications.

6. Support Aquaculture Opportunity Area identification in Alaska

- **a.** Identify regions of optimal growing conditions for common aquaculture species in Alaska.
- **b.** Conduct baseline environmental surveys, as needed.
- **c.** Support broader water quality area classifications in Alaska for bivalve cultivation.
- **d.** Assist in gathering relevant spatial data layers on protected resources, essential fish habitat (EFH), habitat areas of particular concern (HAPC), and socio-economic metrics for AOA spatial analyses.

Appendices

I. AFSC Infrastructure and Resources

A. Ted Stevens Marine Research Institute, Juneau, AK

Located in the State capital of Alaska, this facility is home to analytical and wet laboratory space and offices for personnel in the Auke Bay Labs and other AFSC programs. The Aquaculture Research Lead is based here.

The Genetics program runs the genetics laboratories, with the infrastructure and expertise required to conduct DNA extraction, eDNA analysis using both qPCR and metabarcoding, and population genomic analyses including RADseq and whole genome re-sequencing.

The Recruitment, Energetics and Coastal Assessment (RECA) program applies nutritional and trophic ecology to understanding environmental drivers of condition, growth and recruitment success of ecologically and commercially important species. Capabilities include infrastructure to conduct the following analyses: bulk and compound specific isotopes, %C and %N (& C:N ratios), lipid concentrations, lipid class and total lipids, fatty acids, energy density, moisture and ash, hormones, biomolecules, thiamine, RNA/DNA ratios, chlorophyll-a, and a capacity to readily shift to needs for nutrient concentrations, HABs markers, other vitamins, and other phytoplankton pigments.

The Ecosystem Monitoring and Assessment (EMA) program studies relationships between fish and the environment to improve the accuracy of stock assessments.

B. Little Port Walter Marine Station, Baranof Island, AK

The Little Port Walter marine station is maintained by the Auke Bay Labs division of AFSC and located in a remote region in southeastern Baranof Island, along Chatham Strait. Its proximity to protected waters (Little and Big Port Walters) and high exposed waters (Chatham Strait) makes it a unique resource for field experiments in southeast Alaska. Infrastructure includes housing for researchers and staff, office space, dry labs and equipment (fume hood, pipettes, centrifuge, microscopes, freezers), saltwater net pens (9’ x 9’ x 9’ and 20’ x 20’ x 20’ sizes), large raceways (12,000-21,000 liter volumes), salt- or freshwater tanks with limited temperature control (3,000 L volume), and over 100 small rearing tanks for family-based studies (650 L volume per tank). Additional infrastructure for field-based experiments include dive operations (compressor, dive locker), a 35’ vessel with an enclosed cabin, a 30’ motorized work barge, a 20’ work boat with an enclosed cabin, a 16’ whaler, and two 20’ skiffs.

C. Kodiak Fisheries Research Center and Laboratories, Kodiak, AK

The Kodiak Laboratory houses staff from the Shellfish Assessment and Groundfish Assessment Programs of the Resource Assessment and Conservation Engineering (RACE) Division, as well as staff from other AFSC programs. It provides field and laboratory capacity in one of the major aquaculture regions in Alaska. Field capacity includes an 18 ft skiff, dive operations (dive team, dive locker, air compressor), and proximity to multiple kelp farms and one oyster farm. Wet lab capacity includes a 15,000 ft2 state-of-the-art seawater laboratory; a large selection of tanks of a wide range of sizes and shapes; large, modular, sea water chilling systems; and three 150 ft2 cold rooms. General laboratory capacity includes three bench-top dry laboratories with fume hoods, a range of microscopes and laboratory equipment (drying ovens, muffle furnace, balances, microcentrifuge), a necropsy lab, a walk-in freezer, a -80C freezer, and a Burke-o-lator for seawater carbonate chemistry analysis. The facility is located adjacent to the University of Alaska Fairbanks/Sea Grant Kodiak Seafood and Marine Science Center which houses analytical lab space and a large food science laboratory. There are multiple kelp farms operating around Kodiak Island.

D. Newport Laboratory, Newport, OR

The AFSC Fisheries Behavioral Ecology Program is located at the Oregon State University's (OSU) Hatfield Marine Science Center in Newport, Oregon. The experimental laboratories consist of more than 17,000 cubic feet of tank space housed in over 18,000 square feet of wet laboratory space supplied with 500 gallons per minute of high quality seawater, 200 gallons per minute of which can be chilled to 3° C. Species of current interest include walleye pollock, sablefish, Pacific halibut, and snow crab. The Newport Lab is also home to the Marine Lipids Lab which examines the dynamics of nutritional and foobweb biomarkers. In close proximity is the OSU Molluscan Broodstock Program which works in partnership with the West Coast oyster industry to improve the performance of Pacific oysters through genetic selection.

E. Western Regional Center, Seattle, WA

Below are a subset of AFSC divisions relevant to aquaculture that are based in Seattle.

The Resource Ecology and Fisheries Management (REFM) division of AFSC produces groundfish and crab stock assessments for the management of commercial and recreational fisheries in Alaska. REFM researchers also produce economic and ecosystem assessments to inform fisheries management decisions, including the development of climate-informed stock assessments, management strategy evaluations informed by the modeling of ocean conditions projected under multiple carbon emission scenarios, ecosystem modeling to explore changes in the ecosystem under various habitat use, climate, and fishery harvest resources scenarios (e.g. Ecopath with Ecosim, Atlantis); and editing and communicating annual Ecosystem Status Reports for the North Pacific Fisheries Management Council.

The Economics and Social Sciences Research Program (ESSRP) collects and analyzes economic and sociocultural data to support the conservation and management of Alaska marine resources, and develops models to use those data both to monitor trends in economic and socio-cultural indicators and estimate the economic and socio-cultural impacts of changing markets, environmental conditions, and fishery management measures.

II. AFSC Aquaculture Working Group Members (Name, Division)

- Jordan Hollarsmith, SD, Aquaculture Research Lead
- Todd Miller, ABL - RECA
- Mandy Lindeberg, ABL - RECA
- Charlie Waters, ABL - EMA
- Wes Larson, ABL - Genetics
- Wesley Strasburger, ABL - EMA
- Bridget Ferriss, REFM - REEM
- Cody Szuwalski, REFM - SSMA
- Ben Fissel, REFM - ESSR
- Kim Sheldon, MML
- Erin Richmond, MML
- Chris Long, RACE
- Alix Laferriere, RACE

Gina M. Raimondo
U.S. Secretary of Commerce

Richard W. Spinrad
Under Secretary of Commerce
for Oceans and Atmosphere

Janet Coit
Assistant Administrator
for Fisheries

July 2022

www.fisheries.noaa.gov

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National Marine
Fisheries Service
Alaska Fisheries Science Center
7600 Sand Point Way N.E.
Seattle, WA 98115-6349