FY 22-31 *PROJECT* PROPOSAL
DEVELOPMENT OF MARICULTURE (EXCLUDING FINFISH)

Does this proposal contain confidential information? ☐Yes X No

Project Number* and Title

Project Number 22220302

Sustainable mariculture development for restoration and economic benefit in the EVOS spill area

Primary Investigator(s) and Affiliation(s)

The **Mariculture Research and Restoration Consortium (Mariculture ReCon**) includes:

Alaska Department of Fish and Game (1)
Alaska Fisheries Development Foundation (2)
Axiom Data Science (3)
Native Village of Eyak (4)
NOAA Alaska Fishery Science Center (5)
Prince William Sound Science Center (6)
Shellfish and Seaweed Farmers (7)
University of Alaska Fairbanks (8)

Mariculture ReCon is guided by a Leadership Team that includes Katrina Hoffman (6), Administrative Lead; Ginny Eckert (8), Science Lead; Julie Decker (2), Industry Lead; and John Whissel (4,7), Community Lead. Data management is led by Rob Bochenek (3). Mariculture ReCon components (see Table 1 for more information) are led by Rob Campbell (6), Alysha Cypher (6), Quentin Fong (8), Melissa Good (8), Jordan Hollarsmith (5), Amanda Kelley (8), Brenda Konar (8), Chris Long (5), Alexei Pinchuk (8), Michael Rehberg (1), Anne Schaefer (6), Schery Umanzor (8), and Shellfish & Seaweed Farmers in the EVOS Area (7).

Date Proposal Submitted

March 29, 2021; invited resubmittal August 13, 2021

Project Abstract (maximum 300 words)

The overall objective of the Mariculture Research and Restoration Consortium (Mariculture ReCon) is to support restoration, habitat enhancement, and economic development through research and partnerships between scientists and seaweed and shellfish farmers. This suite of applied research components (Figure 1) takes a farm-centered approach to address EVOSTC restoration, economic development, outreach, administration, and data management interests that overlap top priorities identified by stakeholders and the Alaska Mariculture Development Plan developed by the Governor's Mariculture Task Force. Results will inform shellfish and seaweed production with farmers as full

participants in the research, including the Native Village of Eyak, which has a permit in progress for the largest oyster and seaweed farm in Prince William Sound. Technology transfer and training for new and existing farmers will investigate farm designs and support industry growth, bringing green jobs and economic diversification to coastal communities in the EVOS-affected area. Ecosystem studies will evaluate the role of mariculture in restoration of injured resources, habitat provisioning, reducing ocean acidification impacts, pollution mitigation, and supporting fish populations, while evaluating interactions with marine mammals and birds and developing mitigation strategies. Socioeconomic studies will investigate the economic sustainability of hatcheries, and product development will research new products for this nascent industry. We will host listening sessions in coastal communities and incorporate community feedback into research over the 10-year period to support mariculture development that is responsive to local concerns. Short videos will be created, streamed on social media, and shown in Education & Outreach kiosks to communicate about program activities and inform the public about mariculture. Training of graduate students and postdocs will build capacity, and research collaborations and annual meetings of scientists and farmers will build partnerships and trust that will support sustainable mariculture growth well into the future.

EVOSTC Funding Requested (round to the nearest hundred, must include 9% GA)

FY22	FY23	FY24	FY25	FY26	FY22-26 Total
$2,637,792	$2,637,726	$2,637,783	$2,637,489	$2,637,285	$13,188,075
FY27	**FY28**	**FY29**	**FY30**	**FY31**	**FY27-31 Total**
$2,637,506	$2,637,530	$2,637,458	$2,637,634	$2,636,901	$13,187,030
				FY22-31 Total	*$26,375,105*

Non-EVOSTC Funds to be used, (round to the nearest hundred) please include source and amount per source:

FY22	FY23	FY24	FY25	FY26	FY22-26 Total
$60,239	$62,333	$53,622	$67,787	$111,360	$355,341
FY27	**FY28**	**FY29**	**FY30**	**FY31**	**FY27-31 Total**
$37,689	$39,050	$40,607	$111,937	$128,381	$357,663
				FY22-31 Total	$713,004

1. EXECUTIVE SUMMARY (maximum ~1500 words, not including figures and tables)

The overall objective of the Mariculture Research and Restoration Consortium (Mariculture ReCon) is to support restoration, habitat enhancement, and economic development through research and partnerships between scientists and seaweed and shellfish farmers. This consortium's activities, in turn, will enable capacity building and growth of the mariculture industry in the spill affected area, which will benefit the region that continues to bear the burden of lost revenue and services that the region's ecosystems supported pre-spill. Mariculture ReCon brings together the Prince William Sound Science Center (PWSSC)–a Center of Excellence supported by historical EVOSTC investments–with Alaska Mariculture Task Force members and organizations, Trustee agencies, the Native Village of Eyak, seaweed and shellfish farmers, University of Alaska researchers, graduate students, and post-doctoral scholars to comprehensively address research needs identified in the EVOSTC FY22-31 Invitation for Proposals mariculture focus area.

Mariculture is the term used in Alaska for farming of marine shellfish and seaweeds; finfish farming is prohibited in Alaska. The mariculture industry in Alaska as of January 2020 included 58 aquatic farms, 4 hatcheries and 8 nurseries. By comparison, in August 2021 there were 332 shellfish companies licensed by the Washington State Department of Health[1]. Twenty-eight of the Alaska operations are located within the EVOS-affected area (Pringham 2020). Pacific oysters (*Crassostrea gigas*[2]) are the predominant species, with the largest sales revenue and production (1.8 million oysters sold in 2019) (Alaska Department of Fish and Game 2021). Seaweeds, including sugar kelp (*Saccharina latissima*), bull kelp (*Nereocystis luetkeana*), and ribbon kelp (*Alaria marginata*), are increasing in production, and over 100,000 lbs were harvested in 2019 (Alaska Department of Fish and Game 2021).

The mariculture industry in Alaska is currently small and poised to grow. The Alaska Mariculture Development Plan sets a goal to grow this industry to $100 million in 20 years (Alaska Mariculture Task Force 2018). Between 2017 to 2019 there were 56 applications for aquatic farm permits, and 7 applications to expand existing farms. Mariculture opportunities are tailor-made for Alaska and Alaskans. Alaska's rich and productive waters are well suited for growing shellfish and seaweed, Alaskans are skilled in maritime activities, and Alaska's commercial fishing infrastructure (boats and processing) can serve to jointly support the mariculture industry. Mariculture can benefit ecosystems through habitat provisioning, reducing ocean acidification impacts, pollution mitigation, and supporting

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[1] https://www.doh.wa.gov/Portals/1/Documents/Pubs/332-104.pdf

[2] We use the species name *Crassostrea gigas,* following Bayne et al. (2017). *Magallana gigas* is also accepted.

fish populations (Figure 1), and bring economic benefit through sustainable food production and green jobs.

The Mariculture ReCon project addresses five farm-centered and integrative components that focus on the restoration and economic development potential of mariculture in the EVOS region, in addition to outreach efforts. The research focuses on three regions with active and to-be-permitted mariculture farms: Kodiak, Kachemak Bay, and Prince William Sound (PWS; Figure 2). We will engage shellfish and seaweed farmers in a cooperative research model to evaluate environmental influences of productivity at nine farm sites, with three farms in each of the growing regions. Temperature and salinity will be measured at additional sites by participating farmers to expand the geographic scale of sampling and engage farmers who are interested in lower-level commitment. We recruited eight farms to participate in this research during the EVOSTC proposal revision comment period in June and July. The Native Village of Eyak will participate as one of the farmer researchers in PWS.

In Components 1 and 2, we focus on the ecosystem restoration potential of mariculture. These projects characterize the impacts of mariculture operations to the water column environment, including water column changes driven by mariculture operations and changes to water column communities inside and outside mariculture operations. Macroalgae and shellfish alter the chemistry of the surrounding water column through photosynthesis, respiration, and calcification, and may alter hydrographic conditions due to physical disruptions to the local flow environment (Jackson and Winant 1983). Depending on the scale of these water column changes, the presence of mariculture may alter nearshore habitats, potentially in ways that are beneficial to economically and ecologically important fish and invertebrate species (Dealteris et al. 2004). The objectives in Component 2 investigate if suspended culture techniques used in mariculture in Alaska influence wild biological communities (macroalgae, plankton, benthic communities, pelagic fish, marine birds, and marine mammals) at established farm sites across the study regions (Figure 3a-c) and at bay-wide spatial resolution in PWS (Figure 5). Key to this component is to determine if oyster and seaweed farms influence associated biological communities in similar ways (i.e., similar patterns of change between established and new farms regardless of farmed species or location). The biological community data will be correlated with the environmental data collected in Component 1 to find associations between species and environmental characteristics. Farmers will be important collaborators in collecting data on water column parameters, planktonic communities, fouling organisms on and around farms, marine mammal interactions, and other project objectives.

In Components 3-5, we will investigate methods to increase production and yield on farms with the goal of contributing to the economic development of the region. This work includes better understanding how local and regional variability in water column parameters can influence kelp and oyster growth and survival (Objective 3A), selectively breeding oysters to create Alaska-specific strains for optimized growth (Objective 3B), and kelp farming and harvesting methods for enhanced yield in a growing season (Objective 3C). This research will also evaluate the influences of culturing shellfish and seaweed jointly in

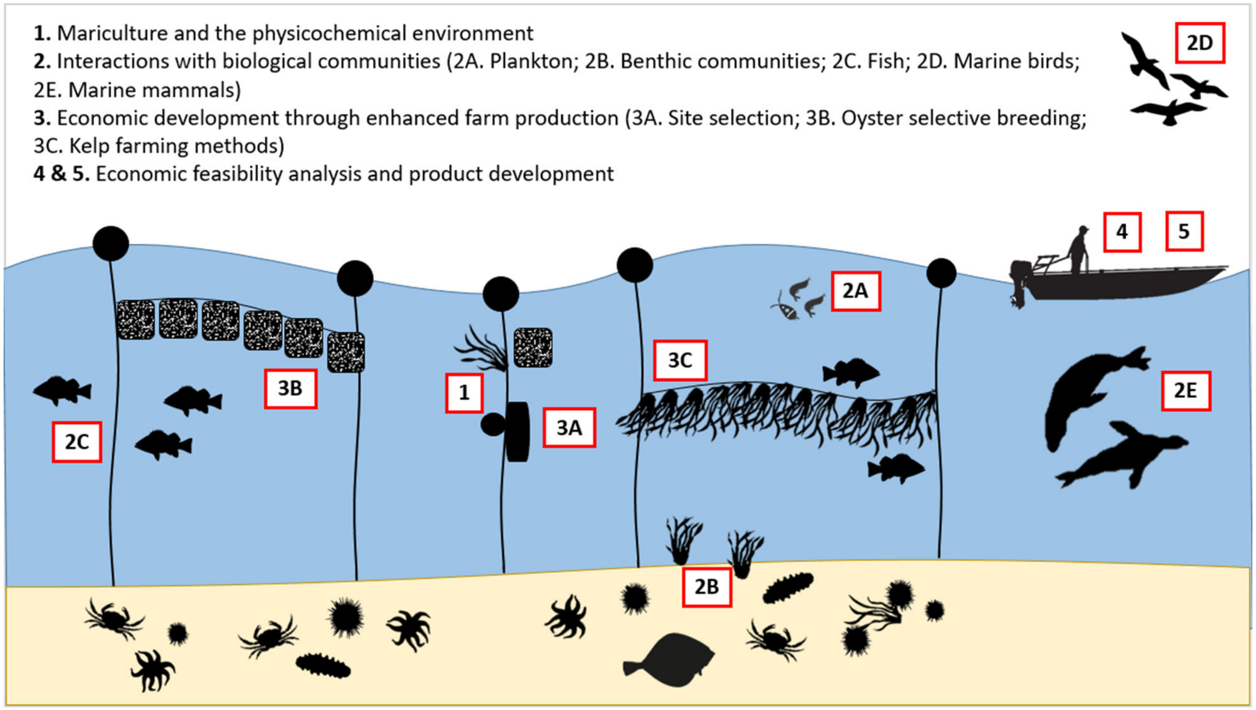


Figure 1. Conceptual design for the FY22-31 Mariculture ReCon research components. This project will evaluate the impact of mariculture on the physical environment (1) and biological communities (2A-2E) in addition to evaluating farm production (3A-3C) and conducting economic analysis and product development (4-5). This multi-tiered program, led by a diverse team of researchers (Table 1) working closely with farmers (Figure 3), will address 30 hypotheses that address the effects of mariculture on multiple levels of biological organization and promote farm production in the spill-affected area (Figure 2). Research will be conducted in collaboration with farmers at farm sites in Prince William Sound, Kachemak Bay, and Kodiak Island (Figure 3a-c). The Mariculture ReCon Program will integrate with existing EVOSTC-funded Gulf Watch Alaska (GWA) long-term research and monitoring (LTRM; Figure 3e, 5). Outreach, data management and project administration complement and support these components.

a polyculture setting through the use of experimental production arrays (Figure 4) located inside operating farms, and the influence of regional variation in water column parameters on farm production. Growing seaweed and shellfish together may increase the profitability and environmental sustainability of mariculture farms by having the outputs of one species balanced by the inputs of the other, therefore benefiting coastal communities and reducing the potential water column impacts of mariculture in the spill zone. Components 4 and 5 will provide critical economic data and product development innovation to address major hurdles in the expansion of the industry. In Component 4, we propose an economic feasibility analysis of hatcheries, specifically an oyster hatchery in Alaska, to determine what resources and infrastructure are needed in order to produce economically viable oyster seed. Component 5 focuses on the development of industry-driven proof-of-concept product forms for seaweed and shellfish that consumers may favor. These seaweed and shellfish prototype products could be adopted by industry to be further developed for large-scale commercial production. Outreach (Component 6), administration (Component 7), and data management (Component 8) round out and support the research and economic development aspects of the project. These three components will be integrated throughout the 10-year project.

A key aspect of our proposal is the outreach component to share our findings with the broader mariculture community. Outreach and community involvement activities will bring together the Mariculture Recon team, the mariculture industry, and the public, including Alaska Native and local community members. We plan to coordinate many outreach and education activities with the proposed Community Organized Restoration and Learning (CORaL) Network to make current scientific information and activities publicly accessible and serve ongoing, community-identified needs. In the Outreach section, we propose outreach activities that pertain to the mariculture industry specifically, including 1) technology transfer, 2) increasing social license of mariculture in the spill area, and 3) hosting regulatory and management workshops. We plan to visit farms, create an information clearinghouse, provide extension and technological support to farmers, offer training workshops, create short informational videos to educate the public about mariculture as well as to share project information, host community listening sessions, answer FAQs about mariculture, and host regulatory and management workshops. The annual Mariculture ReCon meeting will provide opportunities for a two-way dialogue between all researchers and farmers involved in the projects to share interesting research results, observations on the farms, and best practices.

The unified, multifaceted approach described in this proposal was refined through a collaborative prioritization process that included input from the Alaska Mariculture Development Plan (Alaska Mariculture Task Force 2018) research priorities and stakeholder meetings. These components leverage Long-Term Research & Monitoring and Education & Outreach efforts in other EVOSTC-highlighted focus areas to be led by the PWSSC and Alaska SeaLife Center, respectively, if funded. We focus on shellfish and seaweeds that are currently cultured in Alaska and meet the State of Alaska licensing and permitting requirements. Results of this project are non-proprietary and have broad applicability in Alaska.

Table 1. *Mariculture ReCon principal investigators (PI) by component (comp) and objective (obj)*

Comp	Sub-Comp	Obj	PI(s)
1. Mariculture and the Physiochemical Environment		1.1	Hollarsmith (NOAA), Kelley (UAF), Umanzor (UAF), Pinchuk (UAF)
		1.2	
		1.3	Campbell (PWSSC)
		1.4	Hollarsmith (NOAA), Kelley (UAF), Umanzor (UAF), Pinchuk (UAF)
2. Mariculture Interactions with Biological Communities	2A: Plankton	2A.1	Hollarsmith (NOAA), Kelley (UAF), Eckert (UAF), Campbell (PWSSC)
		2A.2	
		2A.3	Campbell (PWSSC)
	2B: Benthic Communities	2B.1	Konar (UAF), Long (NOAA)
		2B.2	
		2B.3	
		2B.4	
		2B.5	
		2B.6	
	2C: Pelagic Fish	2C.1	Cypher (PWSSC), Campbell (PWSSC)
		2C.2	Cypher (PWSSC)
		2C.3	
		2C.4	Cypher (PWSSC), Campbell (PWSSC)
	2D: Marine Birds	2D.1	Schaefer (PWSSC), Rehberg (ADFG)
		2D.2	Schaefer (PWSSC)
	2E: Marine Mammals	2E.1	Rehberg (ADFG), Schaefer (PWSSC)
		2E.2	Rehberg (ADFG)
		2E.3	
		2E.4	
3. Enhancing Farm Production	3A: Regional Variation	3A.1	Hollarsmith (NOAA), Kelley (UAF), Umanzor (UAF), Copeman (NOAA), Miller (NOAA), Suryan (NOAA)
		3A.2	
		3A.3	Eckert (UAF), Decker (AFDF), Good (UAF), Whissel (NVE)
	3B: Oyster Selective Breeding	3B.1	
		3B.2	Hollarsmith (NOAA), Kelley (UAF)
		3B.3	
	3C: Kelp Farming	3C.1	Umanzor (UAF)
		3C.2	
		3C.3	
4. Economic Feasibility		4.1-4.4	Fong (UAF), Good (UAF)
5. Product Development		5.1	Fong (UAF), Sannito (UAF), Good (UAF)
6. Outreach		6.1-6.4	Good (UAF), Decker (AFDF), Eckert (UAF)
7. Administration		7.1-7.3	Hoffman (PWSSC)
8. Data Management		8.1-8.7	Bochenek (Axiom Data Science; To be reported separately)

Acronyms: Alaska Department of Fish and Game (ADFG), Alaska Fisheries Development Foundation (AFDF), Native Village of Eyak (NVE), National Oceanic and Atmospheric Administration (NOAA), Prince William Sound Science Center (PWSSC), University of Alaska Fairbanks (UAF)

2. RELEVANCE TO THE INVITATION (maximum 300 words)

The Mariculture Research and Restoration Consortium brings together the PWSSC—a Center of Excellence supported significantly by historical EVOSTC investments—with Alaska Mariculture Task Force members and organizations, Trustee and management agencies, the Native Village of Eyak, seaweed and shellfish farmers, University of Alaska researchers, graduate students, and postdocs in a suite of components to comprehensively address research needs identified in the EVOSTC FY22-31 Invitation for Proposals mariculture focus area. Together, these collaborators will address EVOTC areas of interest (a) 1. Ecosystem enhancement and restoration through kelp farming; and a variety of subtopics under (b) Research Supporting Mariculture, including, but not limited to items 1, 2, 4, 7, 9, 12, 13, 16, 17, and 18.

The unified, multifaceted approach described in this proposal was refined through a collaborative prioritization process that included inputs from the Alaska Mariculture Development Plan (Alaska Mariculture Task Force 2018) research priorities, stakeholder meetings, and shellfish and seaweed farmers at the Alaska Shellfish Growers Association January 2021 annual meeting. These components leverage Long-Term Research & Monitoring and Education & Outreach efforts in other focus areas proposed to be led by the PWSSC and Alaska SeaLife Center, respectively. The overall goal of Mariculture ReCon is to quantify the extent to which habitat restoration and habitat enhancement occur via mariculture activities and amplify the economic development potential of mariculture by supporting capacity building and growth in the mariculture industry in the EVOS-affected area. Projects focus on shellfish and seaweeds that are currently cultured in Alaska and meet the State of Alaska licensing and permitting requirements. Results of this project are non-proprietary and have broad applicability in Alaska.

3. PROJECT HISTORY (maximum 400 words)

N/A: This is a new project.

4. PROJECT DESIGN:

Overall Objective: Quantify the extent to which habitat restoration and habitat enhancement occur via mariculture activities and amplify the economic development potential of mariculture by supporting capacity building and growth in the mariculture industry in the EVOS-affected area.

This proposed Mariculture ReCon project is a high impact collaboration between government, non-profit, and university-based scientific researchers, mariculture industry professionals, Alaska Native tribal representatives, and farmers who live and work in Alaska (Table 1). Together, we aim to enhance the ability of Alaskan communities to economically benefit from mariculture expansion in a way that restores or enhances the habitats that Alaskan coastal communities in the EVOS spill affected area rely upon. The data generated from our research will be used to:

1. Monitor oceanographic conditions and biological communities as mariculture expands over the next ten years.
2. Evaluate restorative and/or adverse outcomes of mariculture operations on ecological communities.
3. Identify best practices for optimizing productivity, longevity, and site selection of farms.
4. Establish methodology and cost-assessments for generating Alaska-based oyster seed.
5. Address missing supply chain links necessary to move mariculture products to market.
6. Disseminate information to individuals and communities for implementation.

This will be accomplished by addressing 30 research hypotheses within **Restoration Components (1-2)** and **Farm and Business Development Components (3-5)**. These hypotheses will be tested by respective research objectives to generate data that informs the responsible and profitable expansion of mariculture in the spill affected area (Figure 3a-c). The **Project Management Components (6-8)** will disseminate information to stakeholders, provide project administration, and manage data. This work is supported by partnerships with farmers (Figure 3a-c) who will assist with observations and sample collections in addition to guiding researchers about the relevance of research to farm operation and productivity.

Description of Study Area

Mariculture ReCon sites are all within the EVOS spill-affected area defined in Figure 1 of the EVOSTC FY22-31 Invitation for Proposals. We are focusing on three regions with active and to-be-permitted mariculture farms: Kodiak, Kachemak Bay, and PWS (Figure 2).

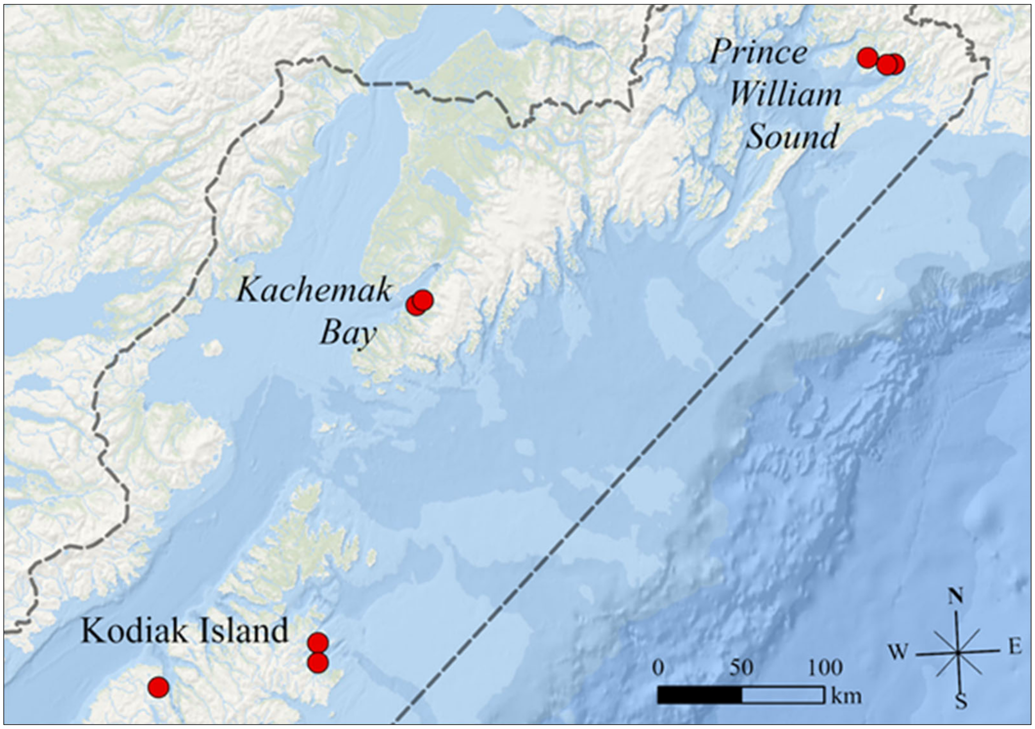


Figure 2. The initial set of study farms (n=8, red circles) selected for this study in Prince William Sound, Kachemak Bay and Kodiak Island regions within the EVOS-affected area boundary (broken line). Additional farms are under consideration for participation, and the set of active study farms may change over time during this 10-year project. Farm selection criteria and details are described in the following section and Figure 3.

RESTORATION COMPONENTS (1-2)

Restoration Objective: Monitor and quantify the extent to which habitat restoration and habitat enhancement occur via mariculture activities.

Rationale: Project components 1 and 2 attend to mariculture interactions with the physicochemical environment and mariculture interactions with biological communities, respectively. These components are oriented towards the ecosystem restoration potential of mariculture in the context of farm interactions with the environment and organisms therein. Kelp and oyster farms may positively or negatively influence the environment in which they are sited; farms have potential to provide ecosystem services such as localized control of ocean acidification, carbon sequestration, marine habitat/refugia for other organisms, water quality regulation, fertilizer provisioning, and more. Components 1 and 2 are oriented towards characterizing the influence mariculture operations have on the physical, chemical, and biological environment and thus determining the extent to which habitat restoration and enhancement may occur as a result of mariculture activities. Collaborative farm partners are key to these components. Here we describe the study area, farm partner types, and the farm partner selection process. Farms are included from three distinct regions within the spill affected area: PWS, Kachemak Bay, and Kodiak. Following farm partner selection description, we delve into component hypotheses, objectives, methods, and analyses. Component 2, mariculture interactions with biological communities, has five sub-components (2A-E), evaluating lower trophic level community interactions with farms (plankton), followed by investigating interactions between farms and other trophic communities (benthic communities, pelagic fish, marine birds, marine mammals).

Farm Types

Kelp. Kelp farming is a new enterprise in Alaska, though coastal Alaska Native communities have long harvested kelp for food and other uses (Stekoll 2019). Currently, there are three operating kelp farms in the EVOS region, with 25 farms permitted to grow kelp. The most commonly grown species is sugar kelp (*Saccharina latissima*), followed by ribbon kelp (*Alaria marginata*), with some farms exploring growing bull kelp (*Nereocystis luetkeana*). Current regulations require that seed (or "spores") for kelp farms are sourced from at least 50 individuals found within 50 km of the farm site (Pring-Ham, 2019). Spores are then settled onto spooled lines in nurseries where they grow to the juvenile sporophyte stage before being transferred onto the farm for the grow-out period. Grow-out on the farm occurs from late fall to spring. Harvest typically occurs between mid-May and mid-June with harvest taking place in early to mid-summer. Many farms recently received permits and are working towards outplanting their first seed in 2021 or 2022.

Oysters. The farming of Pacific oysters (*Crassostrea gigas*, or the newly assigned genus, *Magallana gigas*) has a long history in Alaska, with the first farms appearing in 1910. Currently, there are 23 farms permitted in the EVOS region, though many of these are inactive. Seed for oyster farms are purchased from hatcheries outside of Alaska, most commonly from Oregon, Washington, or Hawaii. The lack of locally available seed within Alaska is one of the major challenges to the sustainability and growth of the industry identified by the Mariculture Task Force (Alaska Mariculture Task Force, 2018). Seed is often grown to larger sizes in FLUPSYs (FLoating UPwelling SYstems) before being outplanted onto farms. Oysters reach market size in approximately three years. Harvest can occur year-round, though most of the growth occurs in the summer when food is plentiful. Oyster farms are often located in protected or semi-protected bays with strong summer phytoplankton blooms. Testing must occur regularly to ensure oysters are not contaminated by paralytic shellfish toxins or other toxins from harmful algal blooms. The *Vibrio* bacteria are also a concern, with farms enacting measures to limit oyster exposures to warm temperatures during the growth phase in the water and during transport. The current dogma is that low ocean temperatures prevent oysters from reaching critical temperatures for spawning in Alaska; however, climate change may alter that balance. Farms in warmer low-latitude states often grow sterile triploid oysters; this proposal includes efforts to assess how yield may differ between fertile diploid and sterile triploid oysters under conditions experienced in Alaska (see Objective 3B.1).

Polyculture. Mariculture operations are increasingly exploring the possibilities of growing kelp and oysters together to diversify their crop and potentially increase yield through mutually beneficial interactions between the kelp and the oysters (3A.2). Sugar kelp, ribbon kelp, and bull kelp (the three major species farmed in Alaska) are a cold temperature crop with a growing season opposite to that of oysters. This difference in timing allows farmers to shift labor and resources from kelp in the cold months to oysters in the warm months. The way in which one crop species can benefit the other will depend (in part) on the way farming systems are set up. While oysters are grown following different approaches (i.e., vertical cages below sea surface, horizontal cages at surface, benthic cages), kelp is typically grown on vertical longlines 2-3 m below the surface. It is possible that biomass sloughed off kelp would benefit oysters grown in proximity with a decreasing beneficial effect increasing with vertical distance between kelp and oysters. Co-production of kelp and oysters is appealing because on the one hand, environmental requirements for both overlap in that they both require high nutrient environments, with adequate water flow, and low freshwater input. On the other hand, co-production reduces the capital investment required to start each crop separately and helps farmers bolster local economies by turning seasonal farm hands into year-round employees. Currently one farm in the EVOS region is harvesting both kelp and oysters, with the kelp being wild-set and not intentionally farmed. Ten farms are permitted for both kelp and oysters, with plans to cultivate both in the future. The Native Village of Eyak is moving forward with plans to install the largest polyculture farm in the region.

Farm Selection

To solicit farmers to serve as collaborators on this project, the Mariculture ReCon team widely distributed a Request for Applications announcement on June 22, 2021, through individual e-mails, team member programmatic listservs, social media, and news articles. Every permitted farmer in the region and people who had taken the recent farm start-up training courses offered through the Alaska Fisheries Development Foundation and Alaska Sea Grant received the notice. In total, 15 farm site applications were received, including:

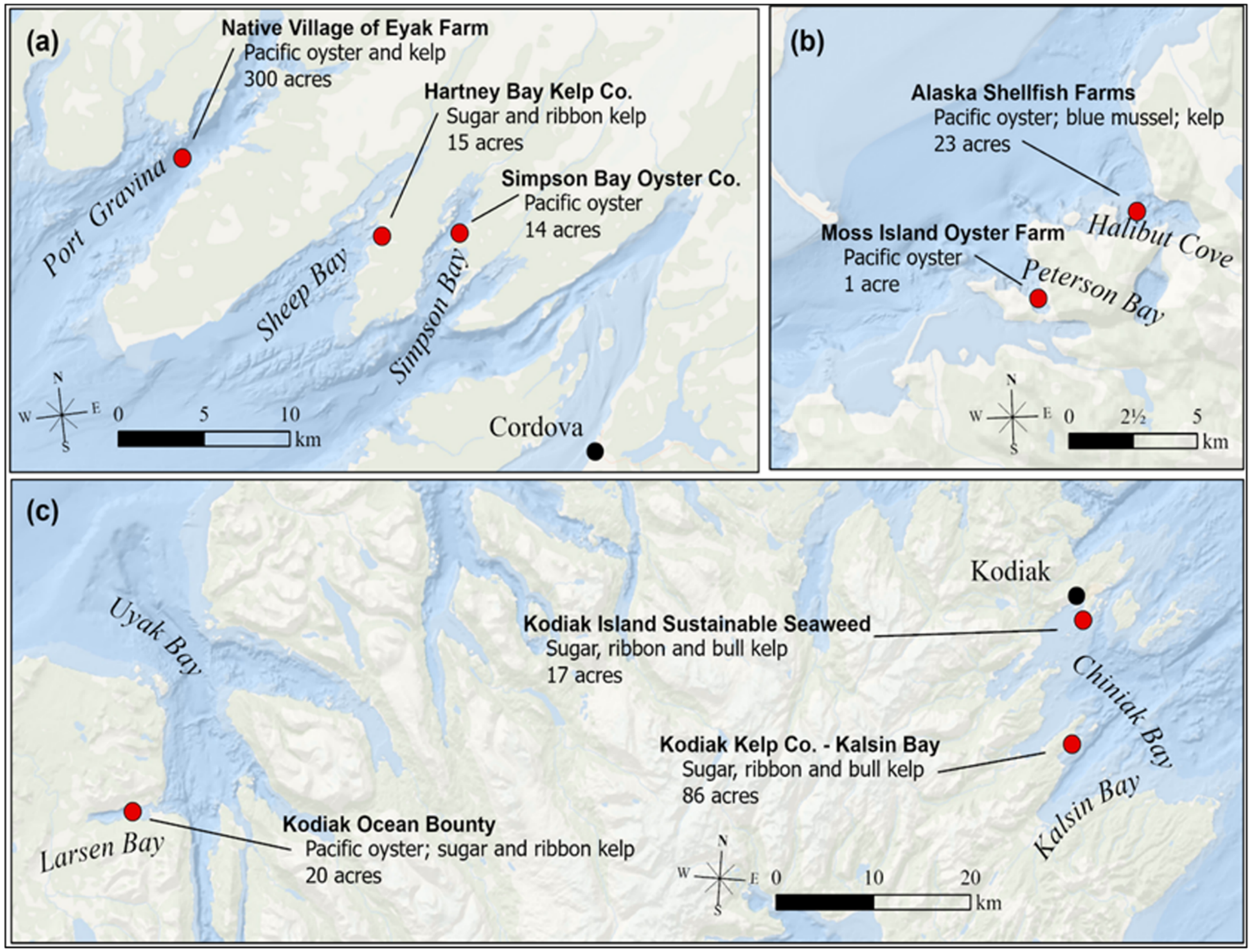
PWS:	5 kelp (4 permitted, 1 pending)
	2 oyster (permitted)
Kachemak:	1 kelp/oyster (permitted)
	1 oyster (permitted)
Kodiak:	5 kelp (4 permitted, 1 pending)
	1 kelp/oyster (permitted)

Farm sites were evaluated based upon location, farm site characteristics, years in operation, experience, and logistics of accessing the site. Farms that were logistically difficult to access and those that are not in operation yet scored lower. Presently, we have selected 8 farms to participate (Figure 3a-c). Our goal is to work with 9 participating farms, 3 from each region. Because we have only 2 applicants from

Kachemak Bay, we are holding one slot open and continuing recruitment in this one region. Selected farm sites range from 20-200 ft in depth with a mean of 80ft and expand over 1 - 300 acres with median size of 19 acres. The Native Village of Eyak, as the Community Lead partner in this project, is included, and their farm site, proposed to be in Port Gravina, is one of the farms in the PWS region. When appropriate, additional farm sites may be invited to participate through providing information or observational data, such as temperature and salinity, to expand the geographic scale of sampling and to engage farmers who are interested in lower-level commitment. One goal of this proposed work is to engage with as many farms as possible to contribute to a community of researchers and farmers.

Partner farmers will work with researchers to install instrumentation to monitor environmental conditions, maintain installed equipment as necessary, collect biological and physical data, make wildlife observations and conduct surveys, maintain open communication with the Mariculture ReCon team and attend an annual meeting. Farmers will be compensated for their time and effort in this project. A new application period for aquatic farmers will be open every three years to accommodate changes in industry growth, new farmer entrants, as well as changes in an individual business. Existing partners will be invited to re-apply to confirm their continued participation.

Partner farmers have agreed to approximately 300 hours/year of project work for three years, including assisting in the installation and maintenance of environmental sensors and sampling equipment on or nearby farms, attending trainings and annual collaboration meetings, offering use of a vessel to access farm site (if needed), accessing an internet connection in order to upload information and participate in remote communications as necessary, collecting data at the farm site at least monthly (year-round), hosting research and industry experts at the farm. Each farm must also have the following insurance policies: (1) Commercial general liability insurance, with property damage; (2) Hull and Machinery Insurance with limits sufficient to cover any vessels the farmer utilizes in the performance of the research; and (3) Protection and Indemnity insurance, with limits of not less than one million dollars ($1,000,000) per event, as applicable for the proposed operations. If any farmer fails to meet requirements, completed work will be paid to date, and the contract will be terminated to preserve the overall research results. Required travel costs will be included in the contract to farmers.



(d) Recon components that will sample at selected farm sites:

Restoration

1) Physicochemical Environment
2) Interactions with Biological Communities
   - A. Plankton
   - B. Benthic Communities
   - C. Pelagic Fish
   - D. Marine Birds
   - E. Marine Mammals

Farm and Business Development

3) Enhancing Farm Production
   - A. Drivers of Regional Variation in Production
   - B. Oyster Selective Breeding
   - C. Kelp Farming Method Development

(e) Region-Specific Objectives

Objectives	Sampling Regions/Farms
1.3	PWS (a)
2A.3	PWS (a)
2C	PWS (a)
2D	PWS (b)
2E.1	PWS, Kachemak (a, b)

Figure 3. Selected farm sites (red circles) for Prince William Sound (a), Kachemak Bay (b), and Kodiak Island (c) with target species and acreage. Project PIs (Table 1) will conduct sampling for Recon components 1-3 (d) across all selected farm sites with the exception of objectives that are region-specific due to adaptation of existing long-term monitoring cruises (e). Note that the location of the Native Village of Eyak Farm in PWS is to be determined.

COMPONENT 1: Mariculture and the Physicochemical Environment

a) Hypotheses and Objectives

Hypothesis 1. Mariculture impacts on water biogeochemistry and nutrient concentrations will be context-dependent, with the greatest impacts found in areas of high seawater residence times.

Objective 1.1: Characterize the local and regional abiotic conditions inside and outside of mariculture operations, including temperature, salinity, dissolved oxygen, carbonate chemistry, nutrients, and photosynthetically active radiation [PAR].

Hypothesis 2. Water biogeochemistry and nutrient concentrations will differ across the regions studied and over the course of the monitoring.

Objective 1.2: Monitor key hydrographic parameters throughout the course of the study across all study regions, including nutrients, temperature, salinity, and dissolved oxygen.

Objective 1.3: Adapt long-term Gulf Watch Alaska oceanographic monitoring to be inclusive of PWS bays expected to have high densities of farms.

Objective 1.4: Measure carbonate chemistry throughout a subset of the study and across all study regions.

Rationale: Macroalgae and shellfish alter the chemistry of the surrounding water column through photosynthesis, respiration, and calcification, and may alter hydrographic conditions due to physical disruptions to the local flow environment (Jackson and Winant 1983). Recent work in a kelp-dominated site in Kachemak Bay, Alaska, demonstrated that although tidal forces largely govern frequency of short-term variability in physicochemical conditions (temperature, salinity, pH, and oxygen), the timing and magnitude of productivity (autotrophy) was greater by a factor of two than in an adjacent bay devoid of macroalgae experiencing the same water mass properties (Miller and Kelley 2021a). Depending on the scale of these water column changes, the presence of mariculture may alter nearshore habitats/services (e.g., macroalgae can increase oxygen production, pH, decrease aragonite saturation state). Such changes can be beneficial to larval and juvenile stages of economically and ecologically important fish and invertebrate species (Dealteris et al. 2004), particularly in response to ocean acidification and deoxygenation (Xiao et al. 2021).

b) Study Design, Procedural and Scientific Methods

Objective 1.1: Characterize the local and regional abiotic conditions inside and outside of mariculture operations, including temperature, salinity, dissolved oxygen, carbonate chemistry, nutrients, and photosynthetically active radiation [PAR].

Objective 1.2: Monitor key hydrographic parameters throughout the course of the study across all study regions, including nutrients, temperature, salinity, and dissolved oxygen.

A suite of sensors will be mounted on production arrays (Figure 4) located inside and outside of nine farms in three bioregions (Figure 2; PWS, Kachemak Bay, and Kodiak, n = 18 arrays) to measure seawater properties, including temperature, salinity, dissolved oxygen, turbidity, and chlorophyll as well as photosynthetically active radiation (PAR). “Inside” refers to sensor array placement (centered) inside of a production farm. “Outside” refers to a site that is in similar water depth, roughly ~200-400 m from the farm, similarly distanced from shore. Autonomous sensors will collect high-frequency data (hourly) of the above listed parameters in FY23-FY29. While variables such as salinity and temperature aren’t expected to be substantially augmented through mariculture activities, these measurements are necessary to calculate other water column properties that are expected to change, including, pH, pCO_2, aragonite saturation state (Ω_{arag}) and apparent oxygen utilization. Additionally, variability in these parameters within a region may have impacts to mariculture production and thus are important to record. Three low-cost current meters (Lowell Instruments TCM-1 Tilt Current Meter) will be installed at each farm site to capture the dynamics of current across the site and in locations where seaweed and shellfish are grown. Discrete water samples will also be collected at the production arrays (Figure 4) to measure nutrient concentrations and to ground truth chlorophyll fluorescence and turbidity ten times yearly.

Farmers will use a CastAway conductivity, temperature, and depth sensor (CTD; Sontek) to capture the salinity, temperature, and depth profile of the water column at production arrays (Figure 4) a minimum of ten times yearly, concurrently with discrete water samples. These CastAway CTDs are quick and easy to use. Data is time and geo-referenced with an internal GPS and can be easily downloaded via Bluetooth. We will provide CastAway CTDs, training, and data management support to participating farmers to expand the geographic scope of environmental data collection for spatial and temporal comparisons and to offer a lower-effort option for farmers that are interested in collecting environmental data but are unable to fully participate as farmer researchers.

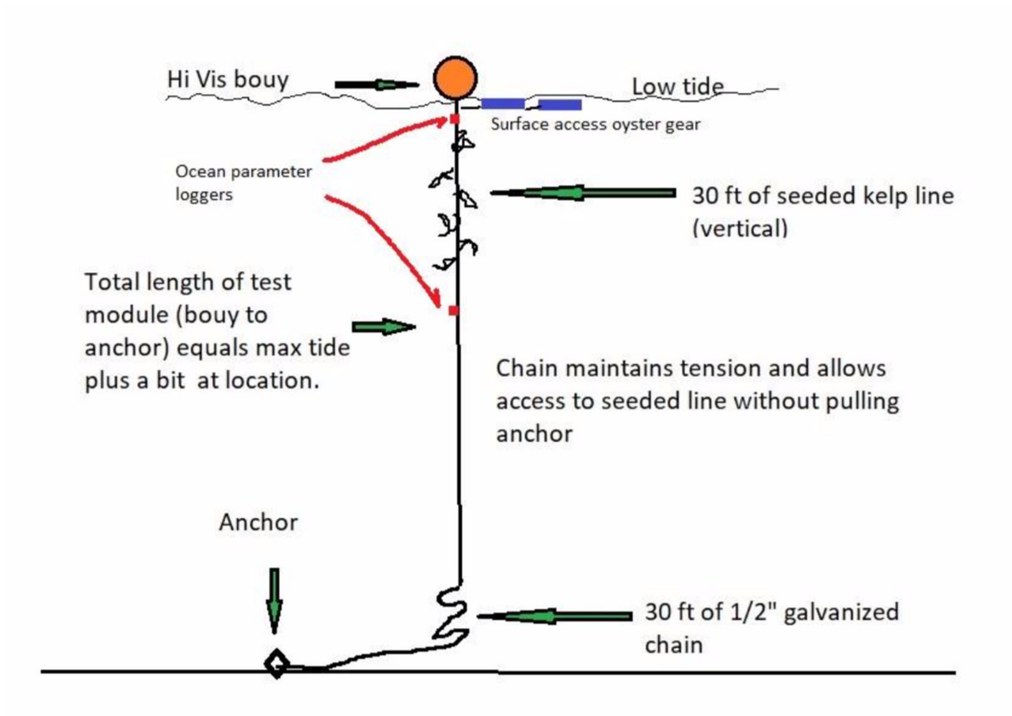


Figure 4. Production arrays that will be implemented inside and outside of farm sites (Figure 3a-c). Each array will host experimental seaweed (on the line) and oysters (in surface gear) as well as oceanographic sensors (drawing not to scale). Arrays will provide data for objectives within component 1 (1.1, 1.2, 1.4), component 2 (2A.2) and component 3 (3A.1, 3A.2).

Objective 1.3: Adapt long-term Gulf Watch Alaska oceanographic monitoring to be inclusive of PWS bays expected to have high densities of farms.

The EVOSTC has funded long term oceanographic monitoring at 12 sites in PWS including Simpson, Zaikof, Eaglek, and Whale Bays (22120114-G; PI Campbell) and marine bird and habitat surveys (22120114-E; PIs Bishop and Schaefer) since 2009 and 2007, respectively. These monitoring programs are proposed to continue until 2031. Here, we propose to expand these surveys by adding bays that are currently being developed for mariculture or have existing oyster and kelp farms. This includes continuing surveys of Simpson Bay (existing oyster farms, proposed kelp/oyster leases) and adding Sheep Bay (proposed kelp/oyster leases), and St. Matthews Bay (no proposed leases, functional control). Two stations will be sampled within each bay: one near the head in proximity to farm sites and one in more open waters at the mouths of bays (Figure 5). Each sampling station will include a conductivity-temperature-depth (CTD, Seabird SBE25plus) cast, and water samples for nitrate, phosphate, and silicate.

Data collected from each station will be used to track changes in oceanographic conditions through time as mariculture develops over the next ten years. Comparisons will also be made between mouth and head sites with proximity to farm sites and farm density/size and between Simpson, Sheep, and St. Matthews (functional control) bays. Complementary sampling will also occur within each farm site (1.1) which provides additional spatial context (farm, bay, region) for the effect of mariculture on ocean physicochemical properties.

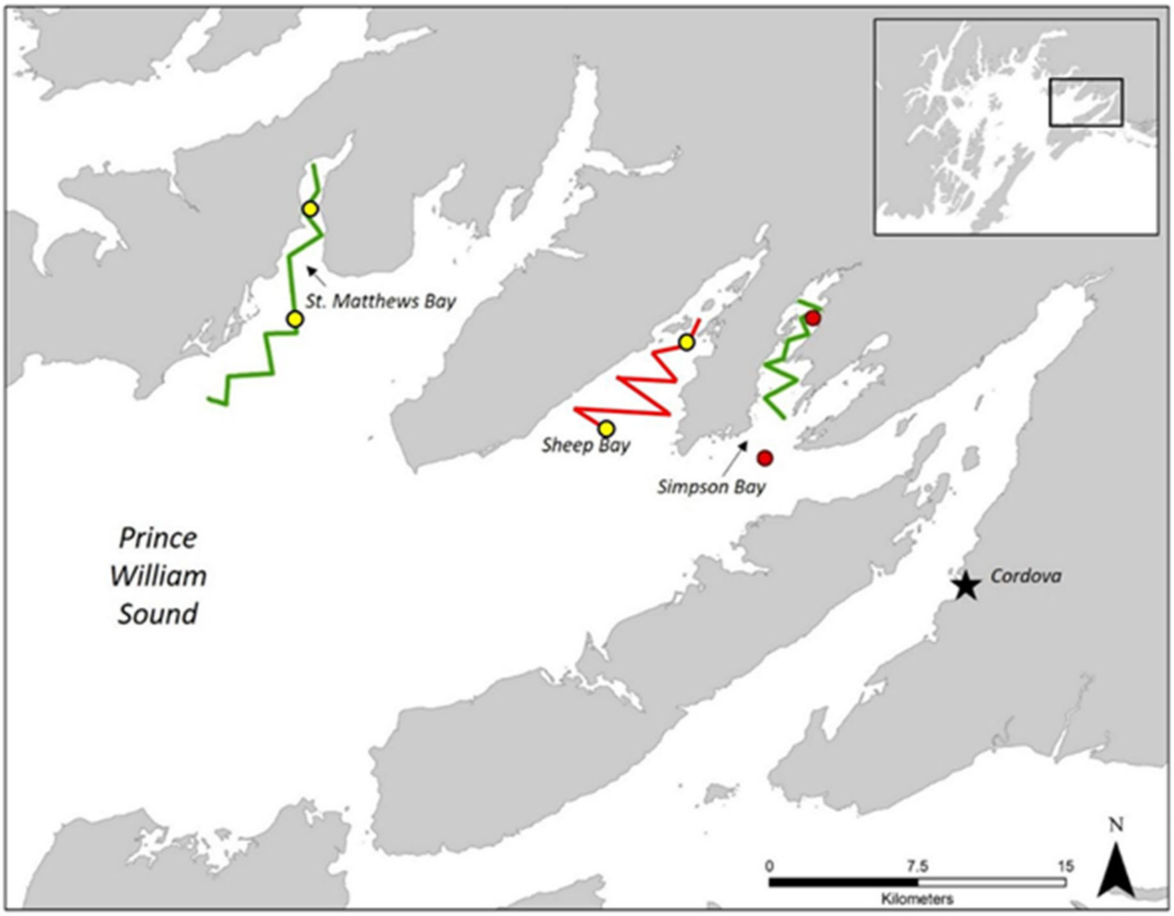


Figure 5. Proposed expansion of existing Gulf Watch Alaska (GWA) long-term research and monitoring (LTRM) programs in eastern PWS, Alaska for objectives 1.3, 2A.3, 2C.1, 2D, and 2E.1 to be inclusive of bays with varying levels of mariculture development (Simpson: existing farms/permits, Sheep: one test-site/several permits, St. Matthews: undeveloped). Current LTRM monitoring includes oceanographic and plankton sampling at stations (red circles; sampled 6-8 times per year; 22120114-G) and marine bird and mammal transects (green lines; sampled 2 times per year; 22120114-E) in Simpson Bay and St. Matthews Bays, respectively. Expansion will add a marine bird/mammal transect (red line) and oceanographic/plankton sampling station (yellow circles) in Sheep Bay), an oceanographic/plankton sampling station in St. Matthews Bay (yellow circles), and hydroacoustic monitoring for pelagic fish (see 2C.1) to all transects. Surveys will occur annually in late winter, spring, summer, and fall.

Objective 1.4: Measure carbonate chemistry throughout a subset of the study and across all study regions.

In a subset of farms, one from each bioregion (n = 3), production arrays (n= 6; Figure 4) will be sampled for high-frequency (hourly) measurements of pH (FY23-FY25) which will be used to fully constrain and describe the carbonate system. In FY22, all instruments will be purchased and/or factory calibrated at Sea-Bird Electronics. Prior to deployment in year two, all instruments will undergo a robust QA-QC at the Kelley lab at UAF, which will include multiple test deployments to ensure all instruments are fully operational (Miller et al. 2018). Deployment of the sensor arrays will occur in year two, and continuous measurements will be collected in FY23-FY25. At each site, a sensor array including a Sea-Bird SeapHOx sensor (which combine the SeaFET V2 pH sensor with the SBE 37-SMP-ODO MicroCAT CTD and DO sensors, measuring pH, temperature, salinity and dissolved oxygen) and a PAR sensor will be deployed within the aquaculture site, and adjacent to the site in each bioregion so that each site experiences the same water mass movement, but differ in terms of the direct influence of biological metabolism (photosynthesis/respiration) produced by the farmed macroalgae and shellfish. Time will be reported as UTC and sampling will occur every hour, continually. This sampling regime allows for short-term analysis of variability and includes both the tidal and photoperiod influence on pH.

The influence of macroalgae/shellfish respiration on seawater chemistry is quantified by capturing high-frequency measurements of pH, salinity, and temperature. Using a robust salinity-total alkalinity (A_T) relationship derived for the Gulf of Alaska (Evans et al. 2015), high-frequency PCO_2 time-series can be calculated, permitting an estimation of local air-sea CO_2 flux. These data are valuable for understanding the potential carbon sequestration capacity of farmed macroalgae. Flux values may be normalized to biomass so that species-specific flux estimates can be generated for a specific kelp farm. With biomass-normalized CO_2 flux estimates, discrete atmospheric CO_2 removal rates may be generated for kelp farms in other regions. What's more, high-frequency estimates of aragonite saturation state (Ω_{arag}) enable an assessment of the benefit of macroalgae to shellfish through the reduction of DIC, thus modifying A_T/dissolved inorganic carbon ratio. Doing so increases the concentration of carbonate ion, creating conditions more favorable for the biosynthesis of calcium carbonate. Recently, much attention has been given to the potential for farmed macroalgae to alleviate impacts of ocean acidification on calcifying organisms through the chemical augmentation of surrounding seawater (Xiao et al. 2021). Although research examining phytoremediation of ocean acidification is in the nascent stages of investigation (Miller and Kelley 2021b), the high-frequency physicochemical measurements collected across three bioregions will no doubt better resolve the ability of macroalgae applied in a polyculture framework to reduce physiological stress from ocean acidification on farmed shellfish or other nearshore calcifying species, especially plankton and larvae. Additionally, we will also quantify the potential carbon flux to the atmosphere and enhanced acidification that may be a result of shellfish farming, a previously understudied area of research (Yang et al. 2021).

c) Data Analysis (If Applicable), Statistical Methods (If Applicable) and Measuring Project Success

Objective 1.1: Characterize the local and regional abiotic conditions inside and outside of mariculture operations, including temperature, salinity, dissolved oxygen, carbonate chemistry, nutrients, and photosynthetically active radiation [PAR].

Objective 1.2: Monitor key hydrographic parameters throughout the course of the study across all study regions, including nutrients, temperature, salinity, and dissolved oxygen.

For all farms between FY23-FY29, inside and outside (n = 18) descriptive statistics and basic time-series analyses will be used to describe the annual range, frequencies, and mean and standard deviation of each parameter (temperature, salinity, dissolved oxygen, and PAR)). Low pass and high pass filters will identify sources of short-term, event-scale and seasonal variability (if present). Pearson's correlation coefficients will be used to correlate all factors: temperature, tidal amplitude, PAR, salinity and O_2 concentration for each farm. This analysis will be couched seasonally, summer and winter. For summer in particular, May – October, pH variability is most extreme in the nearshore Gulf of Alaska (Miller and Kelley 2021a). Relationships will be examined by month at every 3 h time point,240 points per month, for discrete time periods of 30 days (Miller and Kelley 2021a). Relationships during each season will also be assessed using principal components analysis, with site inputs including the seasonal mean of each parameter (temperature, salinity, dissolved oxygen, PAR, and pH).

Differences in parameters across farm region, farm type (oyster or kelp) and location inside or outside of the farm will be determined using a permutational multivariate ANOVA with Euclidean distance matrices. To determine whether mariculture effects significantly differ from natural changes in water properties ("inside vs. "outside"), several statistical approaches will be applied to the annual high-frequency data. An autoregressive integrated moving average model (ARIMA) will be applied to each measurement parameter, and then an F test will be used to compare the model outputs from inside and outside of each farm. Anomaly plots for each parameter will be generated to visually compare inside-outside farm conditions, annually. Oxygen saturation at atmospheric pressure is derived following the methods of Garcia and Gordon (Garcia and Gordon 1992) using measured temperature and salinity values. Apparent oxygen utilization (AOU) will be calculated as the difference between measured in situ concentration and saturation, allowing for a comparison of the duration of net autotrophy/heterotrophy inside and outside each farm site (Miller and Kelley 2021a). To validate whether the inside and outside sites within each farm experience the same water masses, temperature-salinity plots of annual time-series will be generated to visually compare water mass movement with time overlaid in color. To compare physical and chemical differences regionally, descriptive statistics (dynamic range, mean) from each annual time-series (temperature, salinity, oxygen concentration, PAR) will be aggregated regionally to calculate the regional annual mean and standard deviation. To determine directional climate shifts, climatological means will be compared across regions and will be derived by averaging the mean values for each 12-month period over the entire multi-year time-series (FY23-FY29) for each region (Sutton et al., 2019). Inter-annual variability for each region will be calculated by determining the standard deviation of individual yearly means (Sutton et al., 2019).

Objective 1.3: Adapt long-term Gulf Watch Alaska oceanographic monitoring to be inclusive of PWS bays expected to have high densities of farms.

Statistical analysis of oceanographic data for PWS bays with varying degrees of mariculture development will be assessed similarly to the Environmental Drivers Component (PI Campbell; 22120114-G) of GWA. The patchiness of the long-term environmental parameters in space and time confounds standard time-series analysis, and some spatial binning is required to produce time series that are dense enough to analyze. At present, spatially binned data are seasonally detrended with a second order cosine function, anomalies determined from the residuals, and used to detect long term trends. Trends have been examined with standard linear regression and more complicated nonlinear models to incorporate cyclical variations, such as the 18.6-year nodal tidal signal that arises in many geophysical and some biological datasets (e.g., Batten et al. 2016, Campbell 2018). Power analysis has not yet been conducted on these methods and will likely require a Monte Carlo simulation approach to be developed.

The Seabird SBE25plus CTD used in the surveys has an initial accuracy of ±0.001 °C and ±0.0003 S/m for temperature and salinity and drift between annual calibrations has been on order of 0.0002 °C/year and 0.0003 PSU/month, respectively. The Wetlabs FLNTU fluorometer/turbidimeter has a resolution of 0.01 µg l-1 chl-a and 0.01 NTU, and the Seabird SBE43 oxygen sensor has an accuracy of ±2% of saturation and a drift of ~3% per year. Extracted chlorophyll-a has a detection limit of 0.05µg/l. Nutrients will be measured on a Seal Analytical AA3 autoanalyzer; detection limits for nitrate, phosphate and silicate are 0.015 µM, 0.03 µM, and 0.29 µg/l, respectively.

Objective 1.4: Measure carbonate chemistry throughout a subset of the study and across all study regions.

pH time-series and frequency analysis (FY23-25): Voltage measurements recorded by the SeaFET pH sensor will be converted to pH as in Martz et al. (2010) using the single-point calibration method (Bresnahan et al. 2014, Miller et al. 2018) and Mathworks MATLAB software (V. 2018b). All pH reported values are derived from the internal SeaFET electrode given the accuracy, stability, and low inter-sensor variability associated with this electrode (Bresnahan et al. 2014, Gonski et al. 2018, Miller et al. 2018). pH time-series will be characterized across all sites annually, with monthly averages and a 30-day running average reported as a means to enhance the resolution of observed pH variability. Spectral analysis, by season, will be performed on each pH time-series dataset using the pwelch function in MATLAB with a sampling rate of $9.26E^{-5}$ samples sec^{-1} which is equivalent to 8 samples d^{-1} (i.e., every 3 h). A Hanning window will be applied to the pwelch function, and the mean pH value of each month subtracted from the dataset in order to only examine the variance. A 3rd order Butterworth high-pass filter will be designed and applied to the spectral analyses using the butter function in MATLAB with a cut-off frequency of $1.00E^{-5}$.

Uncertainty estimates: For pH calibration, discrete water samples will be collected every three months (collected by the farmer) proximal to each production array (Figure 4). Samples will be stored in glass bottles, fixed immediately with 200 µl saturated mercuric chloride and held in a refrigerator at ~ 4°C until laboratory analysis. pH, DIC and A_T measurements of discrete bottle samples will be made following the *Guide to best practices for ocean CO_2 measurements* (see Dickson et al. 2007) and *Guide to best practices for ocean acidification research and data reporting* (Riebesell et al. 2011). All pH will be measured and reported using the total hydrogen ion scale.

Calibration and reference bottle samples will be assessed for overall accuracy of the pH time-series for each site using propagation uncertainty according to standard operating procedures and best practices in chemical oceanography (Dickson et al. 2007, Orr et al. 2018, Miller and Kelley 2021a). Propagated total uncertainty associated with the pH data will be estimated by combining the calculated uncertainty of our analytical measurements (m-cresol, bottle replicates, titrator and CO2SYS constants), with the discrepancy between our calibration reference samples and measured pH. Analytical measurement uncertainty is given as:

$$Q = \sqrt{\sigma^2_{m-cresol} + \sigma^2_{Bottle\ replicates} + \sigma^2_{titrator} + \sigma^2_{CO2SYS\ constants}}$$

where Q is the propagated uncertainty and SD is the standard deviation of spectrophotometric measurement error from m-cresol validated via triplicate analytical precision using Certified Reference Material (CRM: Batch 172, A.G., Dickson, Scripps Institute of Oceanography), the discrete reference bottle sample replicates, A_T titration duplicates from bottle samples compared against the CRM A_T, and CO2Sys constants. The calculated analytical uncertainty will be combined with the difference between reference bottle pH and sensor measured pH to propagate the uncertainty for all pH time-series. Total propagated uncertainty can vary between 0.01 and 0.04 pH units.

A_T, PCO_2 estimates and flux calculations: Following Miller et al. (2021), salinity recorded by the SBE 37 will be used to estimate A_T using the mean linear regression, A_T-salinity: $A_T = 48.7709*S + 606.23$ µmol kg^{-1} for the Gulf of Alaska (Evans et al. 2015, Siedlecki et al. 2017). A_T estimates will be included with pH to constrain the carbonate system and estimate PCO_2 and aragonite saturation state~Ω_{arg} using CO2SYS: constants Lueker et al. (2000), Uppström (1974), and Dickson et al. (1990). Atmospheric hourly PCO_2 averages will be collected from the nearest NOAA ESRL station and wind speed acquired from automated airport weather observations from the nearest airport adjacent to each site. A CO_2 air–sea flux will be calculated following the bulk transfer method with a gas transfer velocity constant (k) as modified by the Schmidt number (i.e., ratio of kinematic viscosity of water to gas diffusivity), which is a function of temperature and salinity. The bulk flux equation in Wanninkhof (2014) was used for the estimate:

$$F_{bulk} = 0.251U^2.(Sc/660)^{-0.5}K_0(PCO_2w - PCO_2a),$$

where U is wind speed in m s^{-1}, Sc/660 is the Schmidt number calculated using the coefficients from the fourth-order polynomial in Wanninkhof (2014), K0 is temperature- and salinity-dependent solubility of CO_2 in mol $L^{-1}atm^{-1}$ calculated following the model presented in Wanninkhof (2014), and PCO_2 is the partial pressure of CO_2 in water (w) and air (a) in atm (Miller et al. 2021).

Ancillary data analysis and correlations with pH: Temperature, salinity, and dissolved oxygen and PAR data will be analyzed in the time domain for all sites displaying associated pH values. Tidal data will be accessed from NOAA tides and currents (https://tidesandcurrents.noaa.gov/tide_predictions.html) for each site, if available. Spectral analysis for the months of May – September will be performed on oxygen and tidal height predictions. The same methods as above will be used for these frequency transformations—that is, applying the pwelch function in MATLAB with the same sampling rate, high-pass filter, and Hanning window. As before, the mean value for each time-series will be subtracted in order to identify only variation above and below the mean. Pearson's correlation coefficients will be used to correlate pH variability with temperature, tidal amplitude, PAR, salinity and O_2 concentration for each farm for months May – September as this appears to be the time period for which pH variability is most extreme in the nearshore Gulf of Alaska (Miller and Kelley 2021a). Relationships will be examined by month at every 3 h time point, 240 points per 30-day month (Miller and Kelley 2021a).

Nearshore carbonate system model development: Given the expense and technical know-how needed to include carbonate system measurements in water quality monitoring, it is often looked over as a measurement variable. The duration and frequency of physicochemical measurements across multiple regions in Alaska's nearshore yielded here can be used to build multiple linear regression (MRL) models for the estimation of high-frequency carbonate system parameters (Evans et al. 2013). Empirical algorithms of pH and Ω_{arag} will be constructed using temperature, salinity, oxygen concentration, PAR, and nutrient data collected in FY23-FY29. An MRL model approach would greatly benefit regions that may be useful for mariculture purposes, but are data-limited, as both pH and Ω_{arag} are variables critical to determining the site suitability of both macroalgae and shellfish mariculture.

COMPONENT 2: Mariculture Interactions with Biological Communities

2A Plankton

a) Hypotheses and Objectives

Hypothesis 3. Farm development will alter local plankton community composition due to aggregations of forage fish near farms and nutrient release/absorption by oysters and/or kelp.

Hypothesis 4. Suspended mariculture techniques will increase the local diversity and abundance of larval fish and invertebrate species driven by the presence of habitat structure and more favorable water conditions.

Objective 2A.1: Characterize larval and planktonic communities using eDNA and tow nets to determine species richness, diversity, and abundance locally (inside/outside farms) and regionally.

Objective 2A.2: Compare community composition and biomass between farm sites and regions that vary in water column properties.

Objective 2A.3: Adapt long-term Gulf Watch plankton monitoring to be inclusive of PWS bays expected to have high densities of farms.

Rationale: Mariculture operations are known to potentially affect surrounding pelagic habitats by altering water chemical properties and providing new habitats for benthic invertebrates, which may produce dispersive pelagic larvae, and for planktivorous predators. These impacts may ultimately affect zooplankton communities, which play a key role in coastal marine food webs and are highly susceptible to induced environmental changes. Alterations in zooplankton communities may, in turn, lead to shifts in the pelagic food web structure, biological production and export of biogenic materials from coastal areas to the outer ocean. However, little information is available about the effects of farming activities on coastal marine zooplankton communities (Chang et al 2009). Since the main mariculture for local fisheries often shifts from one to the other depending on market economy and demand for fisheries products, it is important to compare and estimate the impacts of different types of aquacultures on coastal ecosystems. Alaskan mariculture farms are often located inside semi-closed fjords with relatively narrow entrances and substantial sills, which typically results in limited exchange of zooplankton populations between the open sea and the inner fjord basin despite substantial tidal flows (Gorsky et al 1999, Rasmussen and Josefson 2002). The main goal of the zooplankton component is to determine if and how seaweed and shellfish farms impact zooplankton communities in the fjords and to identify environmental factors that may facilitate changes in pelagic biological production.

b) Study Design, Procedural and Scientific Methods

Objective 2A.1: Characterize larval and planktonic communities using eDNA and tow nets to determine species richness, diversity, and abundance locally (inside/outside farms) and regionally.

Objective 2A.2: Compare community composition and biomass between farm sites and regions that vary in water column properties.

This sampling effort will occur in FY27-FY29 with the goal of characterizing differences in the planktonic fish and invertebrate communities at production arrays (Figure 4), inside and outside of farm sites, across the EVOS region (Figure 2). Mariculture operations provide truly unique nearshore habitat in that the three-dimensional structure exists primarily in the mid- to surface-water layers and, in the case of kelp, the structure is present for only a portion of the year. We will use a combination of visual plankton identification techniques and environmental DNA (eDNA) analysis. eDNA are the fractions of organismal DNA from skin, scales, or excrement left by an organism when it enters a water mass, and the analysis has been shown to have high spatial and temporal resolution in the nearshore marine environment (O'Donnell et al. 2017).

Zooplankton assessment. At three farms in each of the three regions, inside and outside of the farms (n = 18 production arrays), farmers will conduct plankton tows for visual identification in Dr. Alexei

Pinchuk's laboratory (UAF). Small zooplankton (copepods, meroplankton) will be collected with 150 µm mesh ring nets equipped with General Oceanics flow meters to monitor volume filtered. Oblique tows will be conducted to sample up to 10 m^3 of water with the fine mesh net. Up to three repetitive tows will be conducted at bi-weekly (when possible) intervals during spring months (April-June) to target seasonal peaks in abundance of planktonic larvae (Coyle and Paul 1990), and monthly throughout the rest of the production season. Additional tows will be conducted a week before and a week after kelp harvest. As oysters are harvested throughout the year, with most intensive harvest occurring in the summer, the bi-weekly tows will capture any community changes occurring due to harvest. In addition, an autonomous water pump sampler (Wilborn et al. 2020) will be deployed opportunistically inside each kelp farm at least once a year at locations otherwise inaccessible to net sampling to investigate epibenthic zoo- and meroplankton associated with the structure-forming habitat. Samples will be preserved in 4% buffered seawater-formalin solution immediately following collection and transferred to the lab for later processing. Samples will be processed according to established protocols (Pinchuk and Eisner 2017, Coyle and Pinchuk 2003, 2005). All animals in the samples and subsamples will be identified to the finest taxonomic category possible, and their abundance and biomass will be estimated.

eDNA samples. At one farm site per region at the production arrays inside and outside of the farms (n=6 arrays; Figure 4), farmers will collect eDNA samples from the same depth as the oysters or kelp. Sampling will occur four times per year, including during and outside of the kelp growing season, and five replicate samples will be taken during each time point. Farmers will filter 1 L of water through a 0.2-micron PES filter and preserve the filter in ethanol for shipment to and later analysis in Dr. Wes Larson's lab (NOAA Auke Bay Laboratories). We will use DNA primers that have been developed for fish species, with special attention given to species important in commercial, recreational, and subsistence fisheries in the area (e.g., salmonids, rockfish, cods, eulachons, herring). Extraction, amplification, and sequencing will follow methods in Gehri et al. (2020).

Objective 2A.3: Adapt long-term Gulf Watch plankton monitoring to be inclusive of PWS bays expected to have high densities of farms.

Monitoring will build upon existing GWA surveys in PWS (22120114-G) which include Simpson Bay (existing farms) and expand to include Sheep (permitted leases), and St. Matthews Bays (no leases, functional control) to characterize plankton community composition in bays with varying levels of mariculture development. In addition to the abiotic parameters sampled as part of Component 1 (1.3), phytoplankton and zooplankton vertical tows (202 µm mesh bongo net), inclusive of the top 50 m of surface water, will be conducted at each sampling station (Figure 5). Plankton samples will be enumerated to the finest taxonomic scale under a stereomicroscope as described in McKinstry and Campbell (2018). Expanding existing data sets to be inclusive of mariculture bays will allow for comparisons with historic GWA plankton data sets and temporal changes as farm densities change over the next ten years.

c) Data Analysis (If Applicable), Statistical Methods (If Applicable) and Measuring Project Success

Objective 2A.1: Characterize larval and planktonic communities using eDNA and tow nets to determine species richness, diversity, and abundance locally (inside/outside farms) and regionally.

Objective 2A.2: Compare community composition and biomass between farm sites and regions that vary in water column properties.

Analyses to assess differences between zooplankton communities at production arrays (Figure 4), inside and outside of the farms, will be performed for both abundance and biomass using power-transformed data to stabilize the variance and reduce heteroscedasticity. Analysis of variance (ANOVA) will be used to test for significant effects of location and year/season on the water properties sampled with the production arrays, and the distribution of residuals will be analyzed to ensure it meets the normality assumption. Community similarity will be assessed using the Bray-Curtis similarity index, and community structure will be explored with cluster analysis and non-metric multidimensional scaling (nMDS) using R and PRIMER (v7) (Zuur et al. 2009, Clarke et al. 2014). Significance of the station groups resulting from cluster analysis will be confirmed with PRIMER's SIMPROF routine. Taxa that contribute to community similarity will be identified using PRIMER's similarity percentage (SIMPER) routine. Relationships between zooplankton community composition and environmental variables (temperature, salinity, dissolved oxygen, PAR, nutrients) will be explored with PRIMER's BEST routines using normalized physical data collected simultaneously at the sampling sites. In addition, Generalized Additive Models (GAMs; Wood 2006) will be used to identify significant relationships between zooplankton abundance and water properties that had significant effects on meroplankton distribution.

Taxa identified in the eDNA analyses will be compared to zooplankton tows (2A), visual benthic dive surveys (2B), pelagic fish acoustic imaging (2C.2) for validation. Analysis of eDNA data will follow the same methods as outlined above.

Objective 2A.3: Adapt long-term Gulf Watch plankton monitoring to be inclusive of PWS bays expected to have high densities of farms.

Statistical analysis of plankton distributions for PWS bays with varying degrees of mariculture development will be assessed similarly to the Environmental Drivers Component (PI Campbell; 22120114-G) of GWA. Plankton distributions will be analyzed with a set of common multivariate approaches. Species-by- station matrices will be assigned into clusters by various similarity metrics (Bray-Curtis being the most common). Following clustering, indicator species analysis (ISA) applied to the clusters returns information on the species that define the cluster groups. The impact of environmental parameters on species assemblages will be analyzed with Canonical Correlation Analysis, which permits reducing dimensionality and determining which environmental axes most closely relate to different zooplankton taxa. Multivariate approaches such as these are better described as descriptive (versus inferential), and power analysis is not usually applied.

2B: Benthic Communities

a) Hypotheses and Objectives

Hypothesis 5. The diversity, abundance, and biomass of non-cultivated benthic communities (macroalgae, invertebrates, and fish) will be higher in the immediate vicinity of aquatic farms compared to control sites, driven by the presence of habitat structure, alterations to water column parameters, and increased supply of labile organic material.

Hypothesis 6. There will be no difference in associated benthic assemblages between seaweed and oyster farms.

Objective 2B.1: Characterize benthic communities using SCUBA to determine species richness, diversity, abundance, and biomass inside and outside of aquatic farms.

Objective 2B.2: Determine if benthic communities vary between farm types (oyster versus seaweed).

Objective 2B.3: Determine if and how the role of farm characteristics and environmental parameters correlate with community composition, abundance, and biomass.

Hypothesis 7. Fouling communities found on farm infrastructure, including invertebrates and macroalgae, will be significantly different from natural benthic communities found on hard substrata.

Objective 2B.4: Determine if and how fouling communities on farms differ from associated wild populations found on hard substrate.

Hypothesis 8. The biomass, size, and growth of targeted benthic species such as kelp, sea urchins, sea cucumbers, clams, or other common species, will be higher inside rather than outside aquatic farms, driven by alterations to water column parameters within farms and increased supply of labile organic material.

Objective 2B.5: Characterize biomass, size, and growth of targeted benthic species using SCUBA both inside and outside of aquatic farms.

Objective 2B.6: Determine if and how the role of farm characteristics and environmental parameters correlate with biomass, size, and growth of targeted benthic species.

Rationale: Mariculture operations are increasing around the state of Alaska and have the potential to grow. The Mariculture Development Plan for Alaska suggests that research is needed to continue to develop mariculture in the state, including studies that will quantitatively document environmental impacts of mariculture. While some aspects of this environmental influence have been studied elsewhere in the world, their findings are inconsistent and therefore cannot be applied to Alaska waters without local studies (Crawford et al. 2003, Mallet et al. 2006, Campbell and Hall 2019, Munsch et al. 2021). Mariculture farms may provide enhanced habitat for benthic communities by providing three-dimensional structure and altering water properties and food availability. The objectives of the benthic communities component are to determine if and how suspended culture techniques influence associated benthic communities (fish, seaweeds, and epibenthic and infaunal invertebrates) at established farm sites. Key to this component will be determining if oyster and seaweed farms influence the associated benthic community in similar ways (i.e., similar patterns of change between farms regardless of farmed species). Benthic community data will be correlated with environmental data (2B.3, Component 1), to identify associations between species and environmental characteristics. Lastly, we will work with farmers to identify fouling organisms associated with mariculture farm structure (bags, cages, and lines) and compare fouling communities to naturally occurring benthic communities that occur on hard substrates.

b) Study Design, Procedural and Scientific Methods

Objective 2B.1: Characterize benthic communities using SCUBA to determine species richness, diversity, abundance, and biomass inside and outside of aquatic farms.

Objective 2B.2: Determine if benthic communities vary between farm types (oyster versus seaweed).

We have preliminarily selected three to four established farms of each type (oyster and seaweed) from within the Gulf of Alaska study region (Figure 2). We have selected two sites in Kachemak Bay (Figure 3b,) one site in Kodiak (Figure 3c), and one site in PWS (Figure 3a) for oysters and two sites have been selected in Kodiak, and one site in PWS for seaweeds. Currently, there are no operating seaweed farms in Kachemak Bay. These farms will be our “established farms” if appropriate depths can be found for our methods (SCUBA diving depths). In year one, we will determine the feasibility of these established farms during our first sampling and replace them with other farms if any are deemed too deep. If possible, as the program progresses, up to three new farms of both types (oyster and seaweed) will be sampled in a BACI design. BACI consists of sampling before the farm is set up and then at various intervals once the farm is established. BACI sampling will depend on the proposal, planning, and establishment of new farms.

In addition to our farm sites, we will also designate one control site for each farm within the same embayment/coastline. These control sites will be chosen so they have similar physical environmental characteristics (water depth, exposure, substrate type, and typography). This will allow for a paired sampling design. Benthic community sampling will occur at each site at least once a year using standardized protocols similar to the intertidal sampling done in the nearshore component of GWA At each farm, sampling will occur on both rocky and soft substrates where available and at various water depths (0 m, 5 m, 10 m, 15 m, and 20 m), also where available.

Epibenthic rocky communities: At each farm and control site between FY22-FY25, epibenthic invertebrates and seaweeds inhabiting rocky substrates will be sampled in six randomly placed 50 x 50 cm^2 quadrats along two 30 m transects that follow each depth contour present in each farm site.

Transects will be separated by a random distance. In each quadrat, epibenthic mobile invertebrates larger than 2.5 cm will be identified and counted, kelp stipes identified and counted, and percent cover of sessile organisms (tunicates, sponges, seaweeds, barnacles, etc.) and bare rock estimated. Also, along the 30-m transect, all large and rare organisms (sea stars, sea cucumbers, canopy forming kelp) and benthic fish will be identified and counted within 2 m of the transect. Cryptic fish in sea floor crevices and hiding under algae will be thoroughly searched for using a flashlight.

Macroinfaunal communities: At each farm and control site between FY22-FY25, macroinfauna will also be sampled where soft substrate is found at each site using three replicate 4' diameter PVC cores randomly placed (manually pushed into the substrate to approximately 10 cm depth) along two 30 m transects that follow a depth contour. Each core will be sieved over 2 mm and all organisms identified to larger taxonomic levels and counted. Samples will be dried to a constant mass at 60 C and the mass for each taxonomic level determined. Bivalves will be measured to the nearest mm using calipers.

Objective 2B.3: Determine if and how the role of farm characteristics and environmental parameters correlate with community composition, abundance, and biomass.

Environmental parameters will be measured at each farm and control site to determine correlates with the benthic communities. Farm characteristics will include age and size of farm, cultivated species and cultivation methods. Static environmental variables will be surveyed in FY22 at each site using standardized protocols to characterize the static physical environment. For this, we will classify substrate type, rugosity, exposure (i.e., fetch) and distance to freshwater for each site. Substrate type will be determined along both rocky and soft sediment transects by estimating percent of each substrate classification type in each quadrat using the Wentworth scale (Wentworth 1922; sand (<2 mm), gravel (2 – 6 mm), cobble (6 – 100 mm), boulder (10 cm – 1 m), and bedrock (>1 m)). Average rugosity will also be measured along both rocky and soft sediment transects using the bar and chain method where a 3 m length of chain (5 mm links) is laid along the substrate contour adjacent to each quadrat and then that length is compared to a straight-line distance measured with a 1 m PVC bar (Hamilton and Konar 2007). Fetch will be calculated using the "spoke pattern" method, where vertices will be created every 10° around 360°, at a distance up to 200 m at each farm and control site. These vertices will be clipped whenever they meet with land, using a combination of available data layers (shapefiles) and spatial analyses (waver package) in R. The sum of the clipped vertices will be used to estimate the total fetch at each site.

The distance from each farm and control site to the nearest freshwater source will be calculated in the ArcGIS Pro software version 2.7.1 (ESRI, Redlands, CA). Sources of freshwater will be downloaded from the Alaska Hydrography Database (http://www.akhydro.uaa.alaska.edu) and added as shapefiles along with glaciers and shoreline into the software. Using the geoprocessing Generate Near Table tool, distances from sites to the nearest freshwater source will be calculated, only across water bodies and excluding land masses. We will also determine sediment organic content using loss-on-ignition (LOI) for each farm and control site. For this, 1 cm diameter cores to a depth of 5 cm will be taken, dried to a constant mass at 60 C, and then held in a muffle furnace at 60 C to determine the percent LOI. Dynamic environmental variables (such as temperature, salinity, dissolved oxygen, carbonate chemistry, nutrients, and photosynthetically active radiation [PAR]) will be sampled annually at all sites as part of Component 1.

Objective 2B.4: Determine if and how fouling communities on farms differ from associated wild populations found on hard substrate.

Fouling organisms and mobile species that may be living within the farming cages and lines will be sampled in FY23-FY26 by the farmers either using visual surveys or photographs of a randomly selected number of bags/lines. Visual surveys will consist of examining a set number of lines or cages and counting the number of organisms. For this, farmers will be given a laminated "key" to assist in identifying target organisms. These organisms will be chosen after FY22 sampling. If the farmers would rather take photographs, this will consist of taking three non-overlapping images from a set number of lines of cages. The exact methods and replication will be decided after conversations with the farmers. The same methods will be used to quantify the same suite of species in control sites located in nearby hard substrates outside of the farm area at the same depth as the depth of the gear surveyed.

Objective 2B.5: Characterize biomass, size, and growth of targeted benthic species using SCUBA both inside and outside of aquatic farms.

Objective 2B.6: Determine if and how the role of farm characteristics and environmental parameters correlate with biomass, size, and growth of targeted benthic species.

For FY27-FY30, sampling will be similar to FY22-FY25 except that instead of counts and percent cover, we will collect all mobile invertebrates, and some targeted sessile organisms (sponges, tunicates, hydroids, mussels, and seaweeds) within the quadrats. We will bring these samples to the lab to sort and process. Processing will involve species identification to the lowest possible taxa, counting individuals within species that can be enumerated, obtaining biomass by species or lowest possible taxa, and length for key organisms (sea urchins, kelp, and other common species). We will also tag approximately 20 individual kelps *in situ* in FY27 at each farm and control site using the standard hole punch method to assess kelp growth during subsequent sampling events. Species will be determined based on what is abundant at all sites during the previous years so that we are examining the same species across sites. In addition, 30 individual mussels will be tagged at each farm and control sites and growth will be followed using standard methods in subsequent years. No infauna will be surveyed in FY27-FY30. Decisions about surveying fish in FY27-FY30 will depend on results from the first part of our sampling.

c) Data Analysis (If Applicable), Statistical Methods (If Applicable) and Measuring Project Success

Objective 2B.1: Characterize benthic communities using SCUBA to determine species richness, diversity, abundance, and biomass inside and outside of aquatic farms.

Objective 2B.2: Determine if benthic communities vary between farm types (oyster versus seaweed).

Objective 2B.3: Determine if and how the role of farm characteristics and environmental parameters correlate with community composition, abundance, and biomass.

We will use multivariate statistics (in PRIMER v7 and PERMANOVA C (PRIMER-e ltd, Quest Research Limited; Anderson et al. 2008, Clarke et al. 2014, Clarke and Gorley 2015) to determine differences in the various benthic community metrics (percent cover, abundance, biomass, and density) among years, between farm and control sites, between farm types (assuming that oyster and seaweed control sites are similar), among water depths, and between fouling communities on farm gear and nearby hard substrate. Rocky substrates will be analyzed separately from soft substrates. Biological data will be analyzed with respect to individual species, larger taxonomic level (macroalgae, invertebrates, and fish), and combined taxonomic/ecological groups (e.g., kelp, red algae, filter feeders, predators, etc..) to examine various levels of community patterns. To complement comparisons in community composition with univariate diversity measures, we will calculate the Shannon-Wiener Diversity index and Pielou's Evenness index for each farm and control site and compare the data using ANOVAS (Morris et al. 2014). Means plots will be used to visually determine farm-related trends in taxa deemed important by a SIMPER analysis. Data will be square-root transformed and similarities in communities will be calculated using Bray-Curtis resemblance matrices. Non-metric multidimensional scaling and basic bar graphs will be used to visualize data patterns between farm and control sites and among depths in rocky and soft substrates separately.

Objective 2B.4: Determine if and how fouling communities on farms differ from associated wild populations found on hard substrate.

A Principal Components Analysis (PCA) or a BEST analysis will be carried out using farm characteristics (age and size of farm, cultivated species and cultivation methods), static environmental parameters, and environmental data collected as part of Component 1 to determine the farm characteristics and abiotic variables that best correlate with the biological communities found at the farm and control sites across space and time. Analyses will be done separately on rocky and soft substrate communities. These analyses will be done with respect to individual species, larger taxonomic level (macroalgae, invertebrates, and fish), and combined taxonomic/ecological groups (e.g., kelp, red algae, filter feeders, predators, etc.) to examine various levels of community patterns. PERMANOVA and SIMPER multivariate statistical analyses will be performed using PRIMER v7 to test differences among and between sites and farm types and to identify ecological groups/species that contribute most to those differences. Significance level in all statistical analyses will be set at $\alpha = 0.05$.

Objective 2B.5: Characterize biomass, size, and growth of targeted benthic species both inside and outside of aquatic farms

Objective 2B.6: Determine if and how the role of farm characteristics and environmental parameters correlate with biomass, size, and growth of targeted benthic species.

For each species, size data will be fit to length-mass models using maximum likelihood such that m = aLb, where m is the mass, L the length (or other standardized linear measurement) and a and b are parameters. To determine how various factors affect the regression, we will fit a number of models in which a and b are linear functions of farm (inside/outside), farm type, and region and select the best model(s) using the Akaike's Information Criterion corrected for sample size (AICc). Individual mass, size, and growth will be analyzed using general linear models within each species.

2C: Pelagic Fish

a) Hypotheses and Objectives

Hypothesis 9. Pelagic fish biomass will increase with proximity to high density farming areas within PWS bays and years post-farm implementation.

Objective 2C.1: Adapt long-term Gulf Watch surveys to estimate pelagic fish biomass by echo sounding along gradients of distances from farms within PWS bays.

Hypothesis 10. Forage fish and pelagic fish predators will aggregate within farming structures due to added structural habitat and prey availability.

Hypothesis 11. Schooling density of forage fish associated with farms will be reduced due to added structural habitat as refugia.

Objective 2C.2: Estimate fish abundance, forage fish school density, and body lengths by species associated with farm structures using ARIS sonar imaging and ROV-mounted cameras.

Hypothesis 12. Pelagic fish diversity will increase within farm sites and years post-farm implementation.

Objective 2C.3: Compare species diversity estimates generated from ARIS sonar imaging (2C.2) and eDNA data (2A.1) between farms and control sites over the course of 8 years.

Hypothesis 13. The restorative effects of mariculture expansion in PWS will vary in space and time, particularly with farm density within bays.

Objective 2C.4: Generate EcoPath models that quantify and forecast the effect of farms on ecosystem dynamics, with a focus on ecologically and economically important pelagic fish, in PWS bays.

Rationale: Mariculture operations have the potential to provide refugia for ecologically and economically important pelagic fish species by providing structural habitat for evading predation and buffering capacity against ocean acidification and hypoxia (Visch et al. 2002, Xiao et al. 2021). Therefore, mariculture has the potential to enhance the restoration potential of species and services injured by the EVOS. Here, we propose to use multiple methodologies at varying spatial scales to evaluate how farming structures affect fish abundance, diversity, and behavior as mariculture expands in the spill-affected area and look for sources of co-variation with physicochemical properties (Comp. 1) and prey field (Comp. 2A). This includes genetically detecting fish species from water samples collected within farms (2A.1), estimating fish biomass along transects with varying proximity to farming operations (2C.1), and utilizing sonar imaging and ROV-mounted cameras to assess species diversity, size distribution, and behavior of fish over the course of 24-hour time periods (2C.2). Objectives 2C.1–2C.3 will occur in PWS only (Figure 3a, 5) in order to build off of existing Gulf Watch Alaska (GWA) long-term monitoring (LTRM). This will be the first long-term examination of farm effects to fish assemblages. Consistent monitoring over the course of the Recon program will provide valuable insights into how fish assemblages are affected as mariculture expands and develops (evaluated in 2C.4) in the spill-affected area.

b) Study Design, Procedural and Scientific Methods

Objective 2C.1: Adapt long-term Gulf Watch Alaska surveys to estimate pelagic fish biomass by echo sounding along gradients of distances from farms within PWS bays.

This work will adapt existing quarterly GWA LTRM transects of Simpson and St. Matthews bays by adding an echo sounder to the *R/V New Wave* and adding Sheep Bay (Figure 5). During quarterly sampling cruises, we will use hydroacoustic survey methods that are well established for PWS forage fish surveys (Thorne 1983, Thomas and Thorne 2003, Rand and Thorne 2018) to estimate fish biomass within bays with varying levels of mariculture development. Fixed, zigzag transects (inclusive of nearshore/offshore, inner/outer bay, and distance to farm gradients) will be completed in Simpson (existing farms), Sheep (issued farm leases), and St. Matthews Bay (no leases) four times a year (winter, spring, summer, fall). To estimate fish biomass along transects we will use an echo sounder (Biosonics DT-X) with a 120 kHz split beam transducer mounted downward on the hull of the survey vessel. The echo sounder will transmit pings with the transducer positioned 1-2 m below the surface. The survey vessel will move at a rate of 5 knots during the transect and position will be recorded using a GPS unit. Data generated from hydroacoustic surveys will be used to estimate fish biomass as a function of distance from existing and developing farms and control sites. This data will be collected concurrently with oceanographic (1.3), plankton (2A.3), marine bird (2D), and marine mammal (2E.1) monitoring. Together, this will enhance this multi-trophic level survey by generating concurrent data sets for numerous species that can be used in modeling (2C.4) to estimate the effect of mariculture on ecosystem dynamics in PWS.

Acoustic monitoring has historically been used in PWS to estimate biomass of the Pacific herring population (PIs Thorne, Buckhorn, Rand; 13120111-E, 17120111-G). Our proposed methodology follows the same protocols with three exceptions: 1) biomass estimates will be calculated along a transect with varying distance to farming operations, 2) direct measures from fish capture will not be performed due to expense/logistics, and 3) surveys will be conducted during the day.

The addition of fish echo sounding to these surveys will provide estimates for overall fish biomass along fixed transects between the mouth and heads of Simpson, Sheep, and St. Matthews bays (Figure 5). This data will strictly be used for comparisons of fish biomass as a gradient with distance to varying densities of farms. Comparisons between bays with varying degrees of mariculture development (Simpson-existing farms, Sheep – planned farms, St. Matthews – no plans, functional control) will allow us to resolve whether farms are associated with increased overall fish biomass. Similar methods have been successfully used to identify differences in pelagic fish biomass between areas with seismic disturbances (Slotte et al. 2004).

Direct capture of acoustically detected fish is a means to obtain standard length data for calculating target strength (TS_w), an estimate of area for sonar targets. While current estimates for Pacific herring biomass in PWS utilize direct measures of body length (17120111-G), previous estimates (13120111-E) were validated using ADFG age-sex-length measurements. Validation of fish body lengths is expected to increase the precision of acoustic monitoring, but the relationships between morphology and TS_w is inexact (Boswell et al., 2008). Furthermore, the most significant source of error in acoustic biomass estimates is from mean volume backscattering strength which can inflate estimates by 10% (Boswell et al. 2008). Overall, we expect our estimates to have an error rate of ±30% which is similar to project 13120111-E (PI Buckhorn, Thorne) and that relying on estimates of the relationship between target strength and body length from previous work (Love 1977, Hazen and Horne 2004, Boswell et al. 2008) is adequate for estimating overall pelagic fish biomass along proposed transects (Figure 5).

Past acoustic biomass estimates in PWS for Pacific herring have conducted surveys during the day (13120111-E; PIs Buckhorn, Thorne), and are currently conducted at night (17120111-G; PI Rand). Night surveys are generally more advantageous because fish orient higher in the water column and are more dispersed, leading to less acoustic shadowing. Because this work is taking advantage of already existing day-time surveys, acoustic monitoring for pelagic fish will be conducted simultaneously. While biomass estimates may be higher if conducted during nighttime surveys, consistent daytime surveys will allow for comparisons between transects and as a gradient in relation to farm sites.

Objective 2C.2: Estimate fish abundance, forage fish school density, and body lengths by species associated with farm structures using ARIS sonar imaging and ROV-mounted cameras.

We will use dual frequency, multibeam, imaging sonars (ARIS Explorer 1800, Sound Metrics, 1.1 MhZ, 1.8 MHz, 96 beams) and a remotely operated vehicle (ROV) to estimate size, abundance, and behavior of fish and validate species associated with three farms in PWS and three respective control sites (Figure 6). Imaging sonar has been utilized for previous EVOSTC-funded work to evaluate schooling density for Pacific herring in association with ice shelves (Boswell and Zenone, 2018). We will employ similar methodology to determine how farming structures affect the abundance, species diversity, size distribution, and schooling behavior of pelagic fish. Sonar imaging will complement echo sounder data (2C.1) by providing species-specific estimates of abundance, providing farm-focused spatial resolution, and allowing for comparisons of fish abundance during day and night.

Within each farm site (Figure 6, 7), an imaging sonar will be mounted (either by vessel, ROV, or vane) within or adjacent to farming structures and at respective control sites. Control sites (Figure 6) were chosen based on the depth and proximity to shore as their respective farm sites with at least 1 km between sites. Sonar mounting within individual farms will vary with bottom depth and configuration of farming structures to target fish activity associated with oyster cages and/or kelp lines. Each farm site and respective control will be sampled concurrently with all three bays being sampled within a 30-day time period in late winter (February/early March) and late-fall (November), depending on weather conditions. At each site, recordings will occur for 10 minutes every hour for 48 hours after 4-hr acclimation period once positioned within the site.

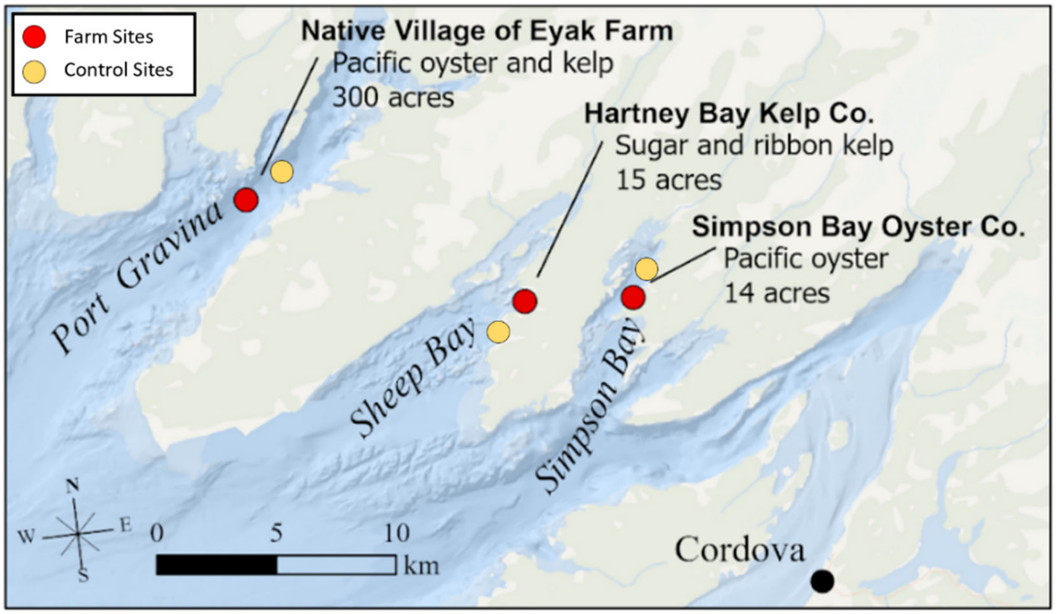


Figure 6. Imaging sonar sites for farms and respective, control sites for objective 2C.2. Control sites are at least 1 km from farm sites and chosen based on similar bottom depth, shore adjacency as respective farm, and expected substrate. Note that the exact location for the Native Village of Eyak Farm and its respective control are to be determined.

While some inferences can be made for species identification from high-resolution imaging sonar, we will use ROV-mounted cameras to validate by species or broad taxa. Additional remotely operated cameras will be affixed to farming structures when possible. The ROV will complete a transect across the area of the multi-beam at the end of the 10-minute sonar recording 2x each day and night. These data will be used in combination with echosounder data to determine how farming structures affect fish abundance, species diversity, and behavior of schooling fish like Pacific herring.

Multibeam imaging sonars provide video-like images from which body length, shape, and behavior can be distinguished and have gained popularity for fish monitoring (Boswell et al. 2008, Shahrestani et al. 2017, Plumlee et al. 2020). Length estimates can vary with fish orientation and angle in addition to bias from position within the viewing field (Hightower et al. 2013). To improve accuracy, we will manually process images for sources of bias and use Echoview Software to filter detections. In comparisons of body lengths by fish species, we expect the error rate to vary up to ± 15% and negatively correlate with fish size based on previous comparisons (Hightower et al. 2013).

Imaging sonar and ROVs have gained popularity for fish surveys and are an effective means of assessing fish abundance, assemblage, and behavior (Zenone et al. 2017, Sward et al. 2019). These technologies in combination with traditional hydroacoustics will allow us to assess broad- (bay-level) and fine-scale (within farms vs control sites) patterns in fish biomass, identify predator presence in relation to forage fish species, and determine if schooling fish, such as Pacific Herring, alter their school behavior within farm structures.

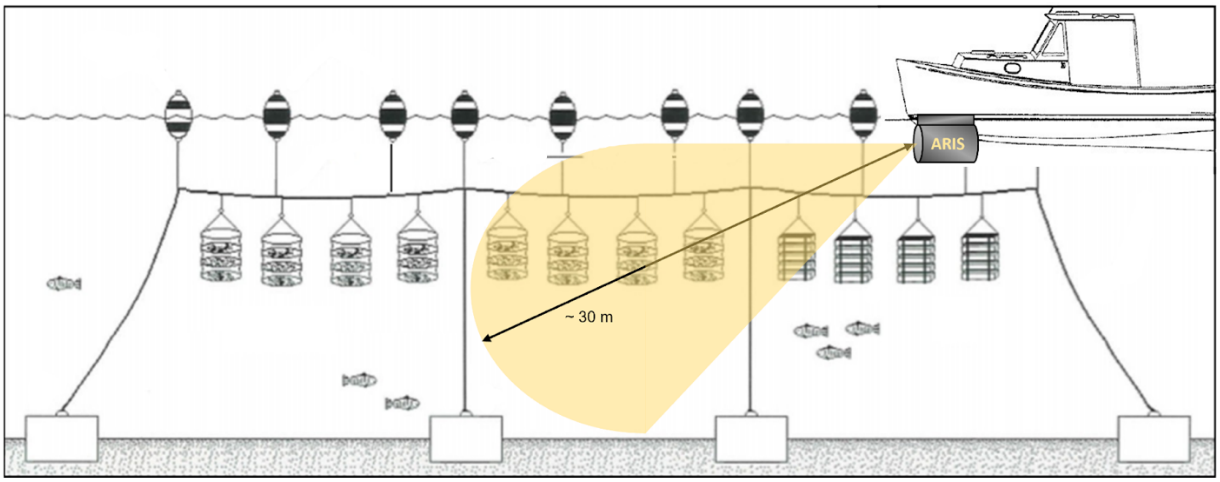


Figure 7. For objective 2C.2, ARIS imaging sonar will be mounted within areas with farming structures including oyster cages and/or kelp lines to detect individual fish. The multi-beam sonar has a high-resolution range of approximately 35 m with a 28° x 14° field of view. Sonar mounting within individual farms will vary with bottom depth and configuration of farming structures to target fish activity associated with the farm.

Objective 2C.3: Compare species diversity estimates generated from ARIS sonar imaging (2C.2) and eDNA data (2A.1) between farms and control sites over the course of 8 years.

We will compare imaging sonar and eDNA data to determine whether farms alter fish assemblages in terms of abundance and species diversity and categorize assemblages through time. Few studies have yet addressed how farming operations affect fish assemblages (Bergman et al. 2001, Cole et al. 2021) or tracked long term effects. Any anthropogenic manipulation of marine environments has the potential to alter habitat usage by fish. While there are hypothesized benefits to mariculture in terms of structural habitat and buffering capacity against ocean acidification (Visch et al. 2002, Xiao et al. 2021), increased vessel traffic, farm activity, and farm density could negatively affect fish habitat (Gentry et al. 2017, Gentry et al. 2020). It is also likely that the benefits and costs of mariculture activity in PWS will vary through time as farm density and productivity increases (Gentry et al. 2020). This proposed work would provide a unique, long-term assessment of fish assemblages over the course of mariculture development in PWS.

Within farming structures, we will validate detected species by cameras (2C.2) and generate counts per species or finest observable taxa. Samples for eDNA within farming structures (2A.1) will also be evaluated for patterns in abundance by taxa as described in Pont et al. (2018). Sonar imaging and eDNA have both been successfully used to evaluate fish assemblages associated with habitats (Plumlee et al. 2020, Pont et al. 2018). Statistical analyses will focus on comparing fish assemblages between 1) survey method (imaging vs. eDNA), 2) farms and control sites, 3) farm type and habitat, 4) farm sizes, and 5) years post-implementation using univariate, multivariate, and linear modeling. Biodiversity will be calculated for each sampling time point and site using the Brillouin's diversity index (HB), which is tolerant of non-random sampling which can be a factor when using multiple sampling methods (Brillouin 1962, Peet 1974).

Accuracy of sampling will primarily depend on the ability to identify observed fish to species during sonar imaging and the integrity and sensitivity of eDNA samples. Species identification will rely upon capturing video of fish detected by the sonar, either by ROV-mounted camera or cameras mounted to farm structures. Evaluation of videos will rely upon resident expertise to identify fish to the finest resolvable taxa. To prevent bias, at least two technicians/researchers will evaluate blinded videos and results will be compared to assess variation by viewer.

While eDNA technology has made significant advancements, detection depends on numerous factors that can affect results. False negative detections can occur due to low sensitivity, eDNA quality, and sampling effort. False positives can occur when samples become contaminated and when DNA markers are not species-specific (Pont et al. 2018). We will evaluate the integrity of farmer-collected eDNA samples (2A.1) to ensure sample integrity each year and make appropriate changes to sampling as needed. DNA primers for species identification will be based off of previous investigations and target species like Pacific herring, salmonids, rockfish, cods, and eulachons which have previously identified by eDNA (Closek et al. 2019).

Objective 2C.4: Generate EcoPath models that quantify and forecast the effect of farms on ecosystem dynamics, with a focus on ecologically and economically important pelagic fish, in PWS bays.

EcoPath modeling will be led by a TBD postdoctoral researcher, hosted at the PWSSC. The postdoc will compile data from the Recon Program (Components 1 and 2) and GWA (Environmental Drivers, Herring Research and Monitoring, Nearshore, Pelagic components) over the course of the Recon Program. This data will be used to perform statistical analyses and construct EcoPath models that 1) Evaluate compiled data for time-series trends, differences between farms and control sites, and categorize ecosystem dynamics in PWS, 2) calculate variation between seasons and years, 3) forecast the effects of farm expansion on ecosystem dynamics and local abundance of species of concern, 4) determine if there is a 'farm carrying capacity' for PWS bays, and 5) examine model usage for other regions.

Data compilation, statistical analysis, and modeling will depend on the expertise of the postdoctoral researcher. Hiring will depend on previous experience in EcoPath modeling, long-term data analysis, and mariculture and/or ecosystem services expertise. The postdoc will be supervised by PIs Cypher and Campbell.

Initial statistical analyses will use linear and multivariate approaches to identify correlations between oceanographic (Component 1) and biological interactions (Component 2) data. This analysis will include examining the normality of data sets, sources of error, and the effect of sampling methodology. Outcomes will be used to identify EcoPath model inputs and relationships between variables (i.e., oceanographic data, zooplankton, benthic species, pelagic fish, and predator abundance). Additional farm variables will be included to assess the effect of structure area, type, and time-post implementation. EcoPath modeling has become a popular software package for estimating the effects of fishing regulations, conservation strategies, and farming effects on energy transfer between trophic levels (for review see Villasante et al. 2016). This modeling approach also allows for forecasting the effect of increases in farm density, alterations in farm structure, and other farm variables to inform best practices for mariculture expansion in PWS.

c) Data Analysis (If Applicable), Statistical Methods (If Applicable) and Measuring Project Success

Objective 2C.1: Adapt long-term Gulf Watch Alaska surveys to estimate pelagic fish biomass by echo sounding along gradients of distances from farms within PWS bays.

Acoustic data generated during zigzag transects will be manually inspected and processed in Echoview software (Sonar Data Ply., Ltd). This software automatically detects bottom and creates a line which will be visually inspected and adjusted accordingly. The data are filtered (-60 dB threshold) to remove smaller, non-fish targets. Echo intensity will be binned in cells by depth and used to generate backscatter measures (area backscatter coefficient, sa (units m2 m-2), or nautical area backscatter coefficient (sA, NASC, units m2 nm-2)) which is exported in a comma delimited file. Echo integration will be limited to the top 60 m of the water column and exclude the 1-m blind-zone near the transducer. If deeper aggregations are encountered, we will adjust the lower depth threshold to extend the survey area into deeper water.

The data generated from Echoview will then be used in R to estimate echo intensity of individual fish and the biomass of fish along the transect. Target strength will be calculated as described in Thorne (1981) by the equation:

$$TS_w = -5.98\, log_{10}\,(L) - 24.23$$

Where TS_w is the target strength (decibels) per unit weight (w) in kg, and L is the standard length of fish in cm. Fish lengths will be estimated acoustically using average TS_w of detected fish calculated by Love's equation (Love 1977). While it would be more accurate to validate fish lengths by trawling for detected fish, adding trawls to the survey would be prohibitively expensive. This method provides a generalized way to estimate fish length without causing mortality while enabling comparisons between farm and control sites. Average backscatter per ping along the entire transect will be calculated by:

$$\bar{s_a} = \sum_{0}^{n} s_{a,n}/n$$

where ($\bar{s_a}$)is the backscatter per ping (m2 m-2), and n is the number of pings along the transect. Lastly, biomass will be calculated by:

$$Biomass = \bar{s_a}/\sigma_{bs} * SA * 1000$$

where SA is the survey area of each bay with varying degrees of mariculture development, estimated by computing the subset of points that lie on the convex hull (chull routine in R, in m2), and 1000 converts kg to mt.

Biomass estimates will be calculated along 3-km segments of survey transects using GIS to spatially join explanatory variables and fish biomass to the midpoint of each transect. Covariates will include temporal, environmental, and farm variables expected to influence fish biomass, including farm density and proximity, distance from shore, and bottom depth. This data will be used to generate plots of fish biomass in comparison to farm distance and density. A GLM will then be used to evaluate the effect of explanatory (farm variables) and environmental (Comp 1, 2A) variables on the response variable, fish biomass over the course of transects and between time points to address hypothesis (H) 9.

Based on previous work in PWS, we expect that the error associated with biomass estimates to be approximately 30%. The inclusion of multiple time points and years of data collection partially circumvents this issue by providing enough statistical power to determine changes in biomass through time. To further address error, we will calculate the range of variances for each survey by applying a non-parametric bootstrap method for each year of data collection.

Objective 2C.2: Estimate fish abundance, forage fish school density, and body lengths by species associated with farm structures using ARIS sonar imaging and ROV-mounted cameras.

Imaging sonar provides high resolution detections that allow for assessment of fish abundance, size, and behavior (Boswell et al. 2008, Boswell and Zenone, 2018). Imaging sonar data will be post-processed in Echoview software using algorithms that have been previously developed for target identification, tracking, enumeration, and biomass estimation (Boswell et al. 2008, Boswell and Zenone 2018). Initial processing will include reducing backscatter via background subtraction, enhancing image quality by implementing a 3 x 3 median filter to detected samples, and tracking of detected targets to allow for instantaneous measurements through time (Boswell et al. 2008). Fish abundance (fish per unit time) will be assessed manually and compared to automated analysis in Echoview (ANOVA).

Schooling density will be derived from estimated nominal beam volume approximated as a rectangular prism and the number of target detections per ping as described in Boswell and Zenone (2018). A down range resolution of < 1 cm for ARIS imaging sonars allows for discrimination of size classes in real time for length-frequency calculations. To calculate length-frequencies, we will first account for fish orientation by manually filtering data after applying an alpha-beta track detection algorithm that will exclude fish that are not orthogonally positioned towards the transducer. Fish density can also be enumerated from this filtered data with fish counts occurring when >5 fish are detected at once and ending 5 seconds after no fish. This method is inclusive of frames without detection in averaging density.

Raw data for abundance, size distribution, and schooling density (forage fish only) by taxa will be compared between farm and control sites using a GLM to determine what explanatory variables (farm type, size, duration) significantly affect response variables (abundance, size, schooling). This analysis will focus on contrasting forage fish abundance vs. fish predators (H11) and schooling density of forage fish like Pacific herring (H12).

The identification of detected fish will be validated by conducting ROV (with camera and light source) transects within the imaging sonar multibeam area. Additional cameras will be mounted within farming structures to assist with identification. Blinded videos will be evaluated by at least two researchers to reduce bias and assess error associated with video processing. Species identification will be used for interpretation of imaging sonar data and to determine how farm structures alter fish assemblages (2C.3).

Objective 2C.3: Compare species diversity estimates generated from ARIS sonar imaging (2C.2) and eDNA data (2A.1) between farms and control sites over the course of 8 years.

Statistical analyses will focus on comparing fish assemblages between 1) survey method (imaging vs. eDNA), 2) farms and control sites, 3) farm type and habitat, 4) farm sizes, and 5) years post-farm implementation to evaluate H12. Biodiversity will be calculated from sonar imaging and eDNA data (for analysis see 2A.1) for each sampling time point and farm site using Brillouin's HB by the following equation:

$$H_B = \frac{\ln N! - \sum_{i-1}^{s} \ln n_1!}{N}$$

where N is the total number of individuals in the sample, ni is the number of individuals belonging to the ith species, and S is the number of species (Brillouin 1962). Calculated diversities will then be compared between imaging sonar and eDNA (ANOVA) to evaluate the utility of eDNA for fish assemblage analyses and corroborate results between the two methods.

Diversity data over time for each farm site will be compared to its paired control within the same rearing bay (Figure 6) to address H12. For each comparison, we will conduct a multivariate and diversity analysis using the "vegan" package in R (https://cran.r-project.org/web/packages/vegan/index.html). Multivariate statistics will include non-metric multidimensional scaling (nMDS) and permutational analysis of variance (PERMANOVA) to compare clusters of fish abundance by taxa between sites. This analysis will be inclusive of covariates that may influence the effect of farms including farm type, bottom-depth and substrate, farm size, and distance from shoreline.

To assess temporal variation with years-post farm implementation, we will use generalized additive model (GAM) to evaluate the effect of explanatory variables (farm type, farm size, time-post implementation, distance from shoreline, habitat characteristics) on the response variable, fish biodiversity, through time (seasonally, annually). This analysis will be expanded to integrate environmental covariates generated from Component 1 and 2 of this proposal to evaluate interactions between fish assemblages and physicochemical properties (1.1-1.3) primary producers (2A, 2B), and potential predation (2D, 2E).

Objective 2C.4: Generate EcoPath models that quantify and forecast the effect of farms on ecosystem dynamics, with a focus on ecologically and economically important pelagic fish, in PWS bays.

The TBD postdoctoral researcher will guide statistical analysis and modeling under the supervision of PIs Cypher and Campbell, but focus on the following goals:

1. Evaluate compiled data for time-series trends, differences between farms and control sites, and categorize ecosystem dynamics in PWS.
2. Calculate variation between seasons and years.
3. Forecast the effects of farm expansion on ecosystem dynamics and local abundance of species of concern.
4. Determine if there is a ‘farm carrying capacity’ for PWS bays.
5. Examine model usage for other regions.

These goals will be met by a series of initial statistical analyses to assess data integrity, identify relationships between variables, and calculate intra- and interannual variability of Recon Program and relevant GWA data sets (FY23-25). Historical long-term GWA data will be incorporated when appropriate to capture pre-Recon Program conditions. This will be followed up with EcoPath modeling (FY25-27) to estimate how farms affect ecosystem dynamics via trophic flow. Models will also be developed to forecast how increases in farm density will influence ecosystem dynamics under varying oceanographic conditions (FY28). Outcomes will be used to estimate how many farms can be supported by bays in PWS (farm carrying capacity). Models will then be applied to Kachemak and Kodiak bays (FY29-30), to assess their utility in other regions and made accessible to other researchers for evaluation in other regions. We will accomplish this by the following statistical framework.

1. Data sources will include Recon Program oceanographic and physicochemical data (Component 1), species abundance associated with farms and control sites (Component 2) in addition to GWA aerial juvenile herring surveys (PI Pegau; 22220111-K), larval herring abundance (PI Cypher; 22220111-H), marine bird surveys (PIs Bishop, Schaefer; 22120114-E), environmental drivers (PI Campbell; 22120114-G), and nearshore (PI

Coletti et al.; 22120114-H) data. Data sets will be filtered by relevant time points and field sites and assessed individually before compilation for normality (a Kolmogorov–Smirnov test and/or a Shapiro–Wilk test) and data gaps. Initial analyses of compiled data will quantify seasonal and annual variation in oceanographic data, species abundance, and farm density/area using a dynamic factor analysis (DFA). DFA is a modern tool for evaluating trends in multivariate time-series data and identifying patterns between data sets (Holmes et al. 2020). Additional farm covariates (type, time-post implementation, etc.) will be added to analysis as needed. The goal of these analyses is to identify correlations between response variables (species abundance) and explanatory variables (oceanographic and farm metrics) for EcoPath model parameterization. EcoPath model balancing will be guided by published pre-diagnostic assessments (Link 2010).

2. DFA of time-series data will provide metrics for seasonal and interannual variability each year. Because oceanographic and species abundance data can be highly variable between sampling points, this is an important metric to be cognizant of for quantifying the effects of mariculture on ecosystem dynamics in PWS.

3. EcoPath modeling will follow similar methods to previous work that has evaluated the effects of anthropogenic manipulation on marine environments (Izquierdo-Gomez et al. 2016; Pezy et al. 2020). Models will be parameterized using spatiotemporal data for species presence and estimated biomass, aggregated by trophic status. Consumption ratios, fishing mortalities, net migrations, biomass accumulation, and natural mortality have already been estimated for PWS (Okey and Pauly 1999) and will therefore be used, in part, to satisfy model equations. These published values will be corroborated by conducting an EcoPath Ecological Network Analysis (ENA) of current data to assess ecosystem structure and functioning in the absence of farm variables. An additional keystoneness index will be performed for species data by trophic status to estimate the importance of ecological roles by species. We expect that pelagic forage fish will have a relatively high importance in comparison to other species. Follow-up models will examine the effect of farm implementation and focus on data, when available, for sites pre- and post-farm development. Trophic flow will be compared between farm and non-farm sites to estimate the effect of farms on ecological dynamics as described in Vilas et al. (2020). Trophic interactions in farm and non-farm areas will then be used to generate models for adjusting farm density, area, and productivity inputs to forecast the effects of mariculture expansion in PWS. This approach has been used previously to estimate the effects of offshore wind farms (Pezy et al. 2020), marine protection areas (Vilas et al. 2020), and artificial oyster reefs (Xu et al. 2019) on ecosystem dynamics.

4. Ecosystem mass-balance models will be generated in EcoPath to estimate the carrying capacity of oyster and kelp farms in PWS as described in (Byron et al. 2011). Briefly, this will be accomplished by modifying farm metric inputs until the model becomes unbalanced and fails to resemble current conditions (Byron et al. 2011, Byron et al. 2015). Carrying capacity will be defined as the point just before model unbalancing occurs. Follow up analyses will estimate carrying capacity in combination with a simulated marine heatwave to determine if carrying capacity decreases with anticipated warming trends (Oliver et al. 2018). The outcomes of this model will be helpful in guiding responsible expansion of mariculture activities in PWS bays.

5. Trophic flow and mass-balance models generated previously will be used to estimate changes in trophic dynamics and carrying capacity for Kachemak and Kodiak regions. Model adaptation for other regions will be assessed by comparing fit between models and comparing outcomes with the expectation that carrying capacity will be similar between all three regions.

2D: Marine Birds

a) Hypotheses and Objectives

Hypothesis 14. Marine bird density and diversity will be higher in the vicinity of farms due to changes in prey availability or behavior.

Hypothesis 15. Marine bird density and diversity will be higher in the immediate vicinity of mariculture developments driven by presence of above-water infrastructure associated with farms.

Objective 2D.1: Quantify the relative effect of mariculture on marine bird density, distribution, and community composition while accounting for the influence of environmental change within and across years and regions using at-sea strip-transect surveys.

Hypothesis 16. Marine bird density, distribution, and community composition will vary across the regions studied and over the course of monitoring.

Objective 2D.2: Adapt long-term GWA marine bird monitoring to be inclusive of PWS bays expected to have high densities of farms and compare these data to the broader gulf-wide context using LTRM GWA monitoring data.

Rationale: Characterizing how the upper trophic level community responds to mariculture development will aid our understanding of mariculture as a restoration tool and inform sustainable and strategic expansion of mariculture within the spill-affected area and in the state of Alaska. As part of this research, we will monitor the effects of mariculture on resources injured by EVOS, including species that have not recovered (pigeon guillemot, marbled murrelet), have likely recovered (black oystercatcher), or have unknown recovery status (Kittlitz's murrelet) (EVOS 2014). Nearshore areas in protected bays are favored mariculture farm locations which overlap with preferred foraging and at-sea habitat for many marine birds (Stocking et al. 2018, Schaefer et al. 2020). Above-water farm infrastructure associated with farms may provide protected sitting and roosting habitat closer to foraging areas. Additionally, underwater structures associated with farms may provide habitat for juvenile fish, acting as an attractant to marine bird predators, altering distribution, density, and community composition patterns.

b) Study Design, Procedural and Scientific Methods

Objective 2D.1: Quantify the relative effect of mariculture on marine bird density, distribution, and community composition while accounting for the influence of environmental change within and across years and regions using at-sea strip-transect surveys.

In conjunction with the marine mammal survey effort (2E), systematic at-sea strip-transect surveys will be conducted in PWS and Kachemak Bay to characterize marine bird density, distribution, and community composition within and across regions. Transects will be designed to encompass on/offshore, inner/outer bay, and distance to farm site gradients (Figure 5) and surveys will occur annually (FY22-29) in late winter, spring, summer, and late-fall to characterize seasonal changes in environmental parameters and ecosystem dynamics. These time frames correspond to kelp farm planting (late fall) and harvesting (late winter), and timing of peak oyster farm activity (spring and summer) and encompass four distinct marine bird communities and life-history stages (Kaler et al. 2017, Schaefer et al. 2020). Snapshot point surveys of marine birds at selected study farms will be recorded during each survey to determine farm-site occupancy and community composition.

At-sea surveys will employ established U.S. Fish and Wildlife Service (USFWS) protocols that have been adapted for GPS-integrated data entry programs (USFWS 2007). One observer will record the number, species, and behavior of marine birds and mammals occurring along a strip transect with a width of 300 m (150 m both sides and ahead of vessel, in distance bins of 50 m). Any noteworthy observations (e.g., forage flocks) will be recorded out to 1 km on either side and flying birds will be recorded continuously. Additionally, sea and weather conditions will be tracked on site by the observer. We will record observations into a GPS-integrated laptop computer using a survey program (SeaLog) developed by Department of the Interior (DOI) agencies and ABR, Inc. SeaLog records GPS locations of the vessel track line and for each entered observation. All marine bird survey groups across the GWA LTRM program use this program, facilitating direct comparison and interpretation of data across different field survey efforts and regions. Differences among survey skiffs across survey regions (PWS, Kachemak Bay) will be standardized and quantified to control for sightability.

Objective 2D.2: Adapt long-term GWA marine bird monitoring to be inclusive of PWS bays expected to have high densities of farms and compare these data to the broader gulf-wide context using LTRM GWA monitoring data.

The EVOSTC has funded long-term monitoring of marine birds in PWS (22120114-E; PIs Bishop and Schaefer) since 2007 and oceanographic monitoring at 12 sites in PWS (22120114-G; PI Campbell). This monitoring program is proposed to continue until 2031. Here we propose to expand these surveys by adding bays in which mariculture is currently being developed or have existing oyster or kelp farms (Figure 5). We will continue marine bird surveys in Simpson Bay (existing oyster farms, proposed kelp/oyster leases) and St. Matthews Bay (no proposed leases at this time and add surveys in Sheep Bay (proposed kelp and oyster leases). We will also increase our marine bird sampling from late fall and late winter to include sampling in spring and summer.

These proposed marine bird surveys will be conducted in conjunction with oceanographic sampling and concurrent hydroacoustic surveys in each PWS study bay. An integrated ecosystem approach including simultaneous collection of upper and lower trophic level data will allow us to characterize impacts of mariculture development on predators as mediated through changes in the prey community.

c) Data Analysis (If Applicable), Statistical Methods (If Applicable) and Measuring Project Success

Objective 2D.1: Quantify the relative effect of mariculture on marine bird density, distribution, and community composition while accounting for the influence of environmental change within and across years and regions using at-sea strip-transect surveys.

Objective 2D.2: Adapt long-term GWA marine bird monitoring to be inclusive of PWS bays expected to have high densities of farms and compare these data to the broader gulf-wide context using LTRM GWA monitoring data.

Using the data from at-sea surveys, as well as existing data collected as part of previous EVOSTC-funded efforts, we will use a regression framework to model marine bird density relative to dynamic and static physical, environmental, mariculture site variables, and prey characteristics within and across years and regions. Density (individuals/km^2) of each marine bird species will be calculated for each 3-km segment of survey transects using the QA/QSea processing program that integrates with the datalogging program, SeaLog. For each 3-km segment, we will use GIS to spatially join explanatory variables and species density values to the midpoint of each transect. Covariates will include temporal, environmental, and mariculture variables known or expected to influence marine bird distribution and abundance (Zydelis et al. 2006, Stocking et al. 2018, Schaefer et al. 2020). For PWS survey data, we will also include synoptic hydroacoustic prey measures as response variables in our models. Temporal covariates will include year and season, and environmental attributes may include in-situ and remotely sensed physical and biological oceanographic measures, bottom depth, distance to shore, and exposure. We will also consider numerous mariculture covariates (e.g., the number and type of farms in each bay, proportional area of bay developed, distance of observations from farm sites) and prey variables (PWS only; biomass/km^2, school density, school size, or school depth). Models will be developed to evaluate the relative importance of environmental attributes, prey characteristics, and mariculture for explaining marine bird and mammal densities and distributions. Community composition and distribution will also be evaluated within and across study areas over time as mariculture activities expand.

2E: Marine Mammals

a) Hypotheses and Objectives

Hypothesis 17. Mariculture development will alter marine mammal density and distribution relative to other areas through competition for space, changes in prey availability or behavior, and/or human disturbance.

Objective 2E.1: Quantify differences in marine mammal presence, density, distribution, and community composition among farmed- and non-farmed sites, while accounting for the influence of environmental change within and across years.

Hypothesis 18. The ways in which marine mammals interact with farms and the level of interaction depends on the mammal species.

Objective 2E.2: Characterize marine mammal interactions with farms using farmer-based surveys.

Hypothesis 19. Marine mammal interactions with farms depend on farm type, equipment used, noise produced, phase of operation, spatial configuration, habitat features and season.

Objective 2E.3: Quantify the influence of farm type and location on the level and type of marine mammal interaction.

Hypothesis 20. Mitigation measures can successfully decrease negative farm-marine mammal interactions.

Objective 2E.4: Discuss, develop, and measure the effectiveness of mitigation measures.

Rationale: Because marine mammal interactions can have a direct impact on farm management decisions, such as selecting farm sites and developing mitigation strategies, agency management decisions, such as permitting, and community perception of farming activity, learning how Alaskan marine mammals interact with Alaskan mariculture farming is crucial. Marine mammal interactions with farms may be positive, negative, or neutral. These interactions include competition for space, entanglement, underwater noise disturbances, displacement from foraging areas and food or behavioral habituation (Clement 2013). By statute, proposed farms may not significantly affect fisheries, wildlife, or their habitats in an adverse manner (AS 16.40.105 (3)). Planning for mitigation measures and avoiding adverse effects must be based on scientific evidence, which is lacking for the scale and environments of Alaska farms (Price et al. 2016).The Alaska Department of Fish and Game (ADF&G), in cooperation with other components of the Mariculture ReCon, will validate successful and environmentally sustainable kelp and shellfish farming practices by coordinating a standardized survey of the direct and indirect interactions of farms with marine mammals. Along with collection and analysis of these data, we will identify potential mitigation steps, among farm site selection, operational timing, and physical barriers, to reduce depredation of farms by marine mammals and potential effects of farms on marine mammals.

b) Study Design, Procedural and Scientific Methods

Overview. The broad project scope is to document farm-marine mammal interactions and develop mitigation tools to address these interactions. The effect of human activity on marine mammals will be tested using response variables that can be measured using visual and behavioral observations

(Fleischman et al. 2016). To this end, among the farm sites and control sites in the project area, we propose to conduct quarterly strip-transect surveys to observe point measures of marine mammal presence and remote time-lapse camera monitoring of nearby pinniped haulouts to observe continuous changes in mammal presence in addition to engaging this project's participant farmers in monitoring behavior of mammals interacting with their farms. For the subset of new farms in development, we will test for changes in marine mammal distribution before construction and then during operation. Because we expect farms to enter and leave the study over the course of its 10-year duration, we anticipate some opportunities to collect baseline data prior to farm construction.

Coordination of field methods between the marine bird (2D) and marine mammal surveys in the Mariculture ReCon project will reduce duplication and allow bird and mammal surveys to be conducted simultaneously by single survey crews. Coordination of field methods between marine mammal surveys and the methods used by the larger GWA program will enable our marine mammal data to be integrated with the GWA database and allow us to use the longer-term, broader results of GWA surveys for comparison with our specific-purpose, local, point surveys.

FY22-FY26 will include quantitative comparison of marine mammal presence at study farms vs control sites and qualitative farmer-conducted surveys of marine mammal interactions. FY25-FY26 will include dissemination of interim results and discussion of potential mitigation measures that are emerging from this work. Surveys will continue along with development, implementation, and assessment of mitigation measures during FY27-FY30. FY31 will focus on data synopsis and dissemination. We will also coordinate data collection with collaborative groups within Mariculture ReCon that are conducting long-term monitoring programs.

Objective 2E.1: Quantify differences in marine mammal presence, density, distribution, and community composition among farmed- and non-farmed sites, while accounting for the influence of environmental change within and across years.

To characterize the effects of mariculture on marine mammal presence, distribution, and community composition, systematic at-sea strip-transect surveys will be conducted in PWS and Kachemak Bay. If feasible, given study site selection and funding, marine mammal surveys will be expanded to Kodiak Island. These systematic, skiff-based at-sea strip-transect and pinniped haulout surveys adopt the methods proposed for marine bird (2D.2) and hydroacoustic surveys (2C.1) in PWS. We will conduct 4 surveys per site per year onboard the same survey cruises (*R/V New Wave)*. Snapshot point surveys at each farm and pinniped haulouts near farm and control sites will be made to determine occupancy. Both transect- and point-surveys will be controlled for mammal sightability distance from the survey platform. For each site we will collect GPS coordinates, date, time, tidal stage, and record the species and number of adults and juveniles present. Observer survey effort along each transect and point survey will be logged for incorporation with models of presence and abundance. Differences among different survey skiffs will be standardized and quantified to control for sightability and observer bias. Observations will be photo-confirmed where possible, especially in cases where mammals carry identifiable markings or show notable behaviors or conditions. Following established pinniped survey protocols, we will take photographs of haul-outs to facilitate accurate enumeration. When possible, marine mammal presence and density information will use data collected during existing GWA nearshore and pelagic ecosystem monitoring.

We will use our standard line-transect surveys proposed to count northern sea otters observed within the survey transect (Davis et al. 2019). Farm platforms will be used to conduct point counts of otters visible from farm sites. While primary sea otter abundance and reproductive trends in the GWA program use aerial surveys (PI Coletti et al.; 22120114-H), our skiff-based work will provide supplemental information on abundance and reproduction. Our standard line-transect surveys will also be used for counts of humpback whales, orcas, and smaller cetaceans. Where possible, to facilitate entry of identified cetaceans in GWA (PIs Matkin Olsen, Durban; 22120114-N), we will collect photographs of body markings wherever possible. Pinniped monitoring will follow established ADF&G and NOAA Fisheries skiff-based survey protocols to facilitate incorporation or distribution (Jemison et al. 2013), density, and individual pinniped identifications (Hastings et al. 2020) with the broader, long-term population surveys of Steller sea lions and harbor seals in the region, along with observations of uncommon pinnipeds, primarily northern fur seals.

At-sea surveys will employ established USFWS and ADF&G protocols that have been adapted for GPS-integrated data entry programs (USFWS 2007) and photo-confirmed pinniped haulout surveys (ADF&G/NOAA standard survey methods, e.g., Jemison et al. 2013). One observer will record the number, species, and behavior of marine mammals occurring along a strip transect with a width of 300 m (150 m both sides and ahead of vessel, in distance bins of 50 m). Observations of marine mammals will be recorded out to 1 km on either side when possible. Additionally, sea and weather conditions will be tracked on site by the observer. To facilitate coordination and data archive, and reduce duplication among mammal and bird surveys, we will use similar logging methods to the bird surveys (2D) by recording observations into a GPS-integrated laptop computer using SeaLog. SeaLog records GPS locations of the vessel track line and for each entered observation.

Data collected by the PWSSC, ADF&G and the GWA LTRM program, will be used to identify and assess existing long-term survey results to characterize general marine mammal seasonal occupancy and abundance. Comparisons will be made against control sites identified by Mariculture ReCon, and the ongoing, surveys and analysis of marine mammal population and behavior conducted by ADF&G, US Fish and Wildlife Service, USGS Alaska Science Center, NOAA Fisheries, Kachemak Bay National Estuarine Research Reserve, and other organizations. At PWS sites, simultaneous collection of upper and lower trophic level data will allow us to characterize impacts of mariculture development on predators as mediated through changes in prey communities. Mammal data generated from this component will contribute to the testing of mammal mitigation strategies during FY27-FY30.

Objective 2E.2: Characterize marine mammal interactions with farms using farmer-based surveys.

As place-based experts of their farms' environment, farm operators are crucial participants measuring the direct interaction of marine mammals with farms. Nine farm sites, three in each region (PWS, Kachemak Bay, and Kodiak Island) will be selected by the Mariculture ReCon for study (Figure 3a-c). Materials, training, reporting tools and feedback for marine mammal observations at the farm sites will be developed with the selected farmers. Materials and training include specification of the research question, data recording forms, methods for collecting marine mammal interaction observations, and description of the anticipated outcomes to this study. Observations for each farm will include:

- Crop type, productivity goals, environmental characteristics, and basic descriptors of farm operations
- Presence/absence of marine mammal species during scheduled farm sampling periods
- Species interactions with farms (e.g., depredation, gear damage, entanglement) during management activities, classified by activity type (e.g., plant-out, harvest, depth adjustments, cleaning, cage pulling)
- Incidental marine mammal presence or interactions outside scheduled sampling periods

We will assess the effects of season, farm type, and location on marine mammal interactions, and use the contracted survey time of the Mariculture ReCon's cooperating farmers to evaluate the types of interactions that occur using a standardized survey. These data will be collected in survey form by contracted farmers and include the mammal taxa present/absent from the farm, basic behavioral observations, and notable marine mammal interactions including depredation, damage, or evidence of attraction. Interaction types will be standardized into a common set of terms used among all farms in the study to facilitate comparison. Specific approaches to analysis will be determined after we develop the survey with the farmers, the full set of focal farms is identified by the Mariculture ReCon team, and the full extent of data collection is known.

Objective 2E.3: Quantify the influence of farm type and location on the level and type of marine mammal interaction.

Continuous measurements of marine mammal presence, absence, and abundance trends provide the key opportunity to measure animal responses to human and environmental factors. Methods for continuous observation include remote time-lapse camera imaging of abundance and continuous acoustic underwater recording. During this study, we will monitor pinniped haulouts near Mariculture ReCon farm sites and control sites to evaluate changes in pinniped abundance over time.

We will install time-lapse (air and/or aquatic) cameras on-site at three farms per region using standard ADF&G protocols for pinniped research used since 2014. Briefly, weatherproof digital cameras will be installed and focused on a pinniped haulout and programmed to take photographs at specified time intervals. Solar panels charge deep-cycle batteries and allow year-round data collection. Data will be retrieved annually. The cameras provide additional, cost-effective, year-round documentation of marine mammal presence and interactions. If the selected farms are in close proximity (< 2.0 km) to an area of documented marine mammal (typically harbor seal and Steller sea lion) terrestrial use (haulout), up to 3 cameras will be mounted near the haulout to capture site specific abundance changes year-round.

Serial photographs of pinnipeds made using remote time-lapse cameras (seals and sea lions) using known haulouts will be analyzed for presence and abundance if selected farms are in close proximity (<2 km). Existing methods developed by ADF&G will be used to optimize data collection from these serial photos to focus counting effort on a smaller, relevant subset while retaining statistical power. Briefly, a short (10-day) complete series of serial photographs will be examined, and the number of animals present in each photo plotted against the number of sequential photos analyzed. Examination of this plot will identify peaks in animal numbers counted, which is then used to determine how many photographs to analyze in the full set (i.e., all photos, 1 of every 5 photos, etc.) to capture animal occupancy and peaks in animal abundance.

Objective 2E.4: Discuss, develop, and measure the effectiveness of mitigation measures.

The culmination of farm-marine mammal interactions documented in FY22-FY26 will lead into the next phase, mitigation development. This component is the key conservation and management-focused feature of our proposal that moves the research performed by the Mariculture ReCon team, farm operators, and cooperators into actionable protocols for site selection, permitting, and mitigation during operations. ADF&G is poised to work with federal managers of marine mammals to develop mitigation measures to reduce impacts resulting from mariculture. Since 2017, ADF&G has discussed the need to evaluate potential impacts and mitigation opportunities with the USFWS and NOAA Fisheries as the mariculture industry began growing in Alaska. Mitigation development is, by its nature, an adaptive study design. Thus, we describe the general approach we will take during this 10-year study to identify, develop, and test potential mitigation methods.

During FY25-FY26, data from marine mammal interactions will be shared with farmers and regulatory agencies in workshops. The location, farm type, specific marine mammal, and type and level of interaction will be starting points for discussions of mitigation measures that conserve both the farms and marine mammals. In FY27-FY30, once potential mitigation measures have been identified, we will work with the farms to implement measures and test efficacy for decreasing interactions. Farms will continue to collect interaction data and we will adjust or change mitigation measures that are unsuccessful. This adaptive work translates the research performed by farm operators, ADF&G, and collaborators into actionable, useful protocols and techniques to reduce marine mammal depredation and injury by creating a list of mitigation best practices. Mitigation will include the following procedures:

- Share summary of farm-marine mammal interactions with farmers and regulatory agencies.
- Working with farm operators, management agency staff, and other Mariculture ReCon PIs, identify a putative set of mitigation best practices that could be used in the farm siting, planning, permitting, and operating phases.
- Implement and monitor a set of mitigation measures at participating farm sites.

- Work adaptively with farm sites to test and adjust mitigation measures and modify practices as necessary based on interim observations and continue monitoring.
- Document successful mitigation measures in a list of suggested best practices.

This phase will integrate quantitative and qualitative marine mammal results and farmer input to collaboratively determine reasonable mitigation methods. Methods may include: site selection considerations, spatial arrangement and timing of farming activity, educational resources, and suggested construction or technology interventions, among other possibilities. Study design will adapt to specific mitigation needs and depend on the type and level of interactions documented by farmers. This portion of our work is necessarily adaptive, dependent on the observations and results collected during FY22-FY26. Specific testing methodology will be specified once survey work is underway and updated with each ReCon annual reporting. As opportunities and solutions arise throughout the duration of this project, we will adaptively investigate potential mitigation practices.

c) Data Analysis (If Applicable), Statistical Methods (If Applicable) and Measuring Project Success

Objective 2E.1: Quantify differences in marine mammal presence, density, distribution, and community composition among farmed- and non-farmed sites, while accounting for the influence of environmental change within and across years.

In cooperation with marine bird survey modeling (2D.1), we will use a regression framework to assess occupancy and density of marine mammals relative to environmental factors along farm site embayment and control survey transects. Because marine mammal sightings are subject to lower sightability than marine birds, we will calculate mammal density and occupancy along 3km survey-segments and for the larger embayments holding the study farms and control sites (i.e., combining observations along the full transect). We will also spatially overlay environmental variables along the 3km survey segments and full farm/control site embayment. Mammal counts at the embayment scale will be modeled against environmental variables (physical factors, season, farm presence and activity) using a generalized additive model (GAM) to account for likely nonlinear covariates. Mammal occupancy (presence/absence) per study site per survey event will be modeled against environmental variables using a logistic regression approach. It is possible an occupancy model methodology may work at the 3km transect-segment scale, but this depends on reviewing the characteristics observations we collect.

Objective 2E.2: Characterize marine mammal interactions with farms using farmer-based surveys.

This objective will see its greatest value for its standardized characterization of interactions and summary statistics to illustrate the different behaviors encountered among different regions, rather than as a statistical modeling exercise. Thus, direct interactions of marine mammals with farm operations will be summarized qualitatively relative to gear type, season, species, phase of operation and other factors.

Objective 2E.3: Quantify the influence of farm type and location on the level and type of marine mammal interaction.

We will use a GLMM framework to account for fixed effects including farm activity phases (e.g., growth, harvest, depth adjustment, gear cleaning, transportation), farm events as reported through Mariculture ReCon participant farmer activity records, environmental measurements, and season, while attempting to detect differences in mammal activity. We will hold individual haulout sites as a random effect. Responses will be animal presence and departure from annual mean abundance, a measure that controls for naturally dissimilar haulout sizes in order to isolate other effects. Environmental parameters also serve as a control for the natural variation in haulout occupancy and abundance. Within-region comparisons will be made between farmed and non-farmed areas. If a farm is in development during the study, we will also assess the displacement of marine mammals by the establishment of new farms by comparing pre-development surveys against post-development surveys as fixed effects.

Objective 2E.4: Discuss, develop, and measure the effectiveness of mitigation measures.

Mitigation development and testing is, by its nature, an adaptive study design. As such, we will not prescribe statistical testing at this early date. Nonetheless, where possible, we intend to conduct mitigation trials using a treatment (mitigation) and control (no mitigation) study design, controlling for environmental and random differences among the treatment and control sites. We will consult the NOAA/NMFS Protected Resources Division Gear Research Team (New England/Mid-Atlantic region) for strategies to reduce risk to protected species as seen in their successful field trials, gear modifications, and work with the fishing industry, manufacturers, researchers, and environmental organizations (Milliken et al. 2020, Usher 2018, Parkins and Smolowitz 2016, Fox et al. 2011). Our work will be modeled on successful mitigation strategies used elsewhere for finfish farming which have reduced predator damage and entanglement of cetaceans and pinnipeds in aquatic farms by implementing anti-predator nets, reducing the mesh size of nets, and ensuring adequate tension on lines and nets (Pemberton 1996; Kemper and Gibbs 1997, 2001).

FARM AND BUSINESS DEVELOPMENT COMPONENTS (3-5)

Development Objective: Amplify the economic development potential of mariculture by supporting capacity building and growth in the mariculture industry in the EVOS-affected area.

Project components 3, 4, and 5 focus on enhancing farm production, creating techno-economical analyses, and developing new products, focusing on three of the most farmed species in Alaska (i.e., oysters, sugar kelp, and ribbon kelp). The increased interest in the cultivation of kelp and shellfish merits optimization of current farming practices, market analysis, and product development to support the expansion of mariculture in Alaska. As such, these three components are oriented towards assessing the feasibility and increasing the profitability of mariculture efforts across different regions affected by the oil spill.

COMPONENT 3: Enhancing Farm Production

3A: Drivers of Regional Variation in Production

a) Hypotheses and Objectives

Hypothesis 21. Growth rates of cultivated kelp and oysters will be greater in regions with higher temperature, nutrient concentrations, pH levels, salinity, and dissolved oxygen (DO) concentration, with oysters showing more sensitivity than kelp to DO and prolonged low salinity exposure.

Objective 3A.1: Characterize the influences of environmental conditions (temperature, salinity, water column stratification, dissolved oxygen, turbidity, chlorophyll, currents, photosynthetically active radiation) on productivity of farmed seaweeds and shellfish across growing areas.

Rationale: The oceanographic setting of seaweed and shellfish farms in the EVOS-affected area is influenced by a variety of factors that vary geographically and may change over time. Understanding these influences will help existing farmers maximize farm outputs and will help prospective farmers place farms in areas that maximize productivity. Shellfish and particularly seaweed farming are new endeavors in Alaska, and while applied research conducted in other regions may be relevant, studies in Alaska are needed to inform best practices for the growing mariculture industry here. Likewise, growing methods and selective breeding may change and improve over the course of the study. Therefore, monitoring the relationship between growth and changing environmental conditions during the full study period will give the most accurate and up-to-date information for the development of the industry. Monitoring of these changes at shellfish and seaweed farms will add to the growing body of knowledge about environmental conditions in nearshore bays in the EVOS-affected area.

Hypothesis 22. In regions of high-water residence times, morphometric and compositional attributes of kelp and oysters will be improved in polyculture settings due to carbon and nitrogen cycling between both species.

Objective 3A.2: Quantify the impacts of polyculture in yield and quality of cultivated species.

Rationale. A polyculture production system requires growing two or more species simultaneously within the same production cycle, with the intent that the presence of both species will be mutually beneficial (Stickney 2013). In some oceanographic contexts, growing kelp and oysters together may increase the profitability and environmental sustainability of mariculture farms by having the outputs of one species balanced by the inputs of the other, therefore benefiting coastal communities and reducing the potential water column impacts of mariculture in the spill zone. Macroalgae photosynthesis results in a draw-down of inorganic carbon in the water column, which, under oceanographic contexts measured in objective 1, could result in more favorable conditions for shellfish development (Connell and Russell 2010, Boulais et al. 2017). The dissolved organic carbon that sloughs off the growing kelp blades may also provide an additional food source for the oysters. Likewise, kelp may benefit from the extra supply of dissolved organic nitrogen derived from the oyster excrement, particularly at scales or sites where nutrients may become limited (Roque D'Orbcastel et al. 2019).

Hypothesis 23. Heavy metal contaminants in farmed and wild seaweeds will vary by site and will be of low levels that pose little to no risk to human health.

Objective 3A.3: Evaluate the spatial and temporal occurrence in contaminants in farmed and wild seaweeds.

Rationale: Seaweeds can rapidly accumulate elevated concentrations of metals and metalloids, especially heavy metals, from both natural and anthropogenic sources (Chen et al. 2018). These sources of contaminants can vary by site and can also vary over time. Seaweed markets and regulators are concerned about these contaminants. For example, commercial seaweed products must be tested and fall below threshold standards for products to be imported and sold into European markets. Consequently, contaminant testing is essential to access certain markets and is also important for health and safety concerns of seaweed grown as a food source. This accumulation trait of seaweeds makes seaweed farming a potential environmental remediation tool in polluted areas. Thus, seaweed farming could be used as a restoration tool to confer environmental remediation benefits (such seaweeds would not be appropriate for human consumption). Data from this project will inform the development of safe seafood operations and contribute to ensuring the safety and quality of cultured seafood products. Our results will inform seaweed growers, resource managers, agency personnel, and community groups of potential contaminant levels. Expected outcomes from testing seaweeds for contaminants include creating a better understanding of seasonal and year-to-year variation in seaweed contaminants, differences in contaminants among seaweed species, relationships between contaminant concentrations in farmed (growing mid-water away from shore) and wild-harvested seaweeds (growing on the benthos nearshore), and an understanding of the risk associated with seaweed consumption that could potentially have impacts on human health or have implications in accessing international markets. Currently, the FDA and USDA do not regulate the sale of seaweed in its whole form as a food product. Without federal guidance on the food safety risks of seaweed in its whole form, states, including Alaska, are unsure how to proceed with their own laws and regulations, impeding the growth of the industry. The data on seaweed contaminants will be important in informing future regulation to ensure safe food products.

b) Study Design, Procedural and Scientific Methods

Objective 3A.1: Characterize the influences of environmental conditions (temperature, salinity, water column stratification, dissolved oxygen, turbidity, chlorophyll, currents, photosynthetically active radiation) on productivity of farmed seaweeds and shellfish across growing areas.

We will engage shellfish and seaweed farmers in a cooperative research model to evaluate environmental influences of productivity at nine farm sites, with three farms in each of the growing regions: PWS, Kachemak Bay, and Kodiak (Figure 3). Temperature, salinity, dissolved oxygen, carbonate system, nutrients, and photosynthetically active radiation [PAR] will be measured at each farm site each during Component 1 sampling. Temperature and salinity will be measured opportunistically at additional sites to expand the geographic scale of sampling and engage other farmers who are interested in lower-level commitment. We aim to engage with as many farms as possible to contribute to a community of researchers and farmers. Opportunistic data collected from additional farm sites (besides those in Figure 3a-c) would be useful for:

- incorporation into the production analyses
- incorporation into the ecosystem analyses
- the use of temperature and salinity as a proxy for other water column parameters, such as nutrients or pH, to develop an approximate idea of region-wide oceanography (in combination with LTRM data collection efforts).

Production arrays: Each production array (Figure 4) will be positioned inside and outside of mariculture operations (n=18 arrays) and include an experimental oyster rack and seeded kelp line, allowing us to concurrently monitor water column parameters and oyster and kelp metrics. To assess differences in important kelp and oyster physical and biochemical metrics in polyculture vs. monoculture installations, we will focus initially on experimental arrays (FY23-FY25) and opportunistically shift sampling to commercial farms as the use of polyculture farm designs increases over time (FY26-FY29). Specifically, we will focus our analyses on kelp grown on production arrays located within oyster farms, and oysters grown on production arrays within kelp farms. This approach considers that the biomass in the production array is unlikely to be large enough to influence the farm where the array is installed but the biomass of the farm would affect the production array.

Objective 3A.2: Quantify the impacts of polyculture in yield and quality of cultivated species.

Oyster Farm Production Arrays: We will collect morphometrics data on 10 oysters per production array inside and outside of kelp farms once per year to obtain maximum shell length and width, shell strength and thickness, in addition to elemental composition of the shell. Shell attributes will be used as a proxy to evaluate the effect of changes in water chemistry (carbonate system) driven by kelp as well as the influence of local water chemistry on shell characteristics. Three times per year, four oysters will be collected at a subset of farm sites and processed for condition factors such as wet and dry meat weight to shell dry weight, total organic content (Jones and Iwama 1991), total lipids per organic mass (Lu et al. 2008), as well as total fatty acids and polyunsaturated fatty acid composition per weight (Copeman and Parrish 2004). All sampled oysters will be processed for biomarkers such as bulk isotopes of carbon and nitrogen (Marchias et al. 2013) and individual fatty acids (Copeman et al. 2009); select subsamples based on the range of bulk isotope values will be run for compound specific isotopes (Rowe et al. 2019). These metrics provide indicators of oyster condition and energetic pathways (e.g., whether oysters are feeding more on phytoplankton or kelp detritus in a polyculture context; Both et al. 2020). Fatty acid results will also give an estimation of the quality of different farm sites for future mariculture development. Omega-3 fatty acids, in particular, are important to the shellfish industry as they are used to define oyster nutritional quality (Tan et al. 2020). Tissue samples will be processed by the NOAA-OSU Cooperative Institute Marine Lipids Lab and the NOAA Recruitment, Energetics, and Coastal Assessment (RECA) Program at the Auke Bay Laboratories.

Kelp Farm Production Arrays: A total of 10 kelp fronds will be collected from the production arrays inside and outside of oyster farms 60 and 30 days prior to when they reach harvestable size (approximately May). Fronds will be processed at the farm sites to obtain morphometrics of maximum blade length, width, and thickness, maximum stipe length and diameter, and wet weight. Depending on the infrastructure at the farm, samples will be shipped to the Ted Stevens Marine Research Institute (TSMRI) for measurements of dry weight, ash weight, and elemental carbon and nitrogen content. An additional four kelp samples will be collected at the same time points in a subset of farms and sent to TSMRI to measure total fatty acids, polyunsaturated fatty acid composition, bulk isotopes, and compound specific isotopes. Tissue samples will be processed by the NOAA-OSU Cooperative Institute Marine Lipids Lab and the NOAA Recruitment, Energetics, and Coastal Assessment Program at the Auke Bay Laboratories.

Farm Production: Farmers will be invited (but not required) to share farm production data, in terms of numbers of oysters or pounds of seaweed harvested per year. These data are the same as those collected annually by the state of Alaska and held in confidence by management agencies. We will arrange confidentiality agreements with those who choose to share data to set terms by which these data will be used in this study.

Polyculture Farms. Once sampling commences at commercial polyculture farms, kelp and oysters will be sampled at varying distances from the other species, with precise sampling design dependent on the setup of the polyculture installation. The goal of sampling designs will be to determine the spatial scale of interactions between both species. Kelp and oysters will be processed to obtain the same morphometric and composition measurements at the same temporal frequency, as described above.

Objective 3A.3: Evaluate the spatial and temporal occurrence in contaminants in farmed and wild seaweeds.

Three replicate samples from up to three species of cultivated seaweed will be collected from nine farms and paired control sites using proper handling methods which decrease the potential for contamination of samples. Samples will be taken during the harvest period (April-June) during FY23 and FY25, frozen, compiled for each of the three regions and shipped to the lab for contaminant testing, including arsenic, mercury, lead, cadmium, tin, copper, silver, molybdenum, antimony, and bismuth. The results will be analyzed against regulatory requirements for food safety. Based on those results, a subset of sites, either those showing contamination in concentrations over regulatory limits or a random collection of sites, will be sampled during FY27-FY31.

c) Data Analysis (If Applicable), Statistical Methods (If Applicable) and Measuring Project Success

Objective 3A.1: Characterize the influences of environmental conditions (temperature, salinity, water column stratification, dissolved oxygen, turbidity, chlorophyll, currents, photosynthetically active radiation) on productivity of farmed seaweeds and shellfish across growing areas.

Summarization of the environmental parameters measured on the production arrays (Figure 4) will be drawn from Component 1. In brief, descriptive statistics and basic time-series analyses will be used to describe the annual range, frequencies, and mean and standard deviation of each environmental parameter (temperature, salinity, dissolved oxygen, turbidity, fluorescence, and PAR). Low pass and high pass filters will identify sources of short-term, event-scale and seasonal variability (if present). Pearson correlation coefficients will be used to examine correlations among environmental parameters.

Objective 3A.2: Quantify the impacts of polyculture in yield and quality of cultivated species.

Statistical analyses in FY23-FY25 will focus on morphometric and compositional differences between oysters grown on production arrays (Figure 4) inside and outside of kelp farms, and kelp grown inside and outside of oyster farms across the different oceanographic contexts in the study region. In FY27-FY29, analyses will also account for the placement of each species in a farm, or the distance of a sample from the closest other species (e.g., the distance of an oyster sample from a section of the farm growing kelp).

Correlation matrices will be constructed to explore correlations between morphometrics. Multivariate analysis of variance (MANOVA) will be used to explore significant differences in oyster and kelp morphometric traits in production arrays inside vs. outside a farm, and in a polyculture vs. monoculture installation, including distance from the alternate species. In addition to comparing the performance of individual traits, we will work together with farmers to generate a performance index based on a list of desirable characteristics per species and using all data collected. The influence of oceanographic context on morphometric traits will be investigated using linear models, with a given morphometric trait as the dependent variable, and the principal components coordinates as the independent variable (Hollarsmith et al. 2019). The results of these linear models will reveal which water masses yield more favorable growth, thus giving insight into both the role of oceanographic context and farm design (polyculture vs. monoculture).

Compositional analyses. These analyses will focus on resolving the energetic pathways between kelp and oysters in a polyculture setting. The compositional quality of oysters will be defined both as total lipids per weight as well as with individual fatty acids per weight (% and mg/g) and other compositional metrics important for the aquaculture industry (i.e., sum omega-3 fatty acids). The contribution of kelp to oyster nutrition will be explored using multivariate analyses of all compositional parameters. Fatty acid proportions > 0.5% in kelp and oysters, total fatty acids per WWT, and bulk carbon and nitrogen isotopes will be analyzed using PRIMER v.7 (Primer-E) with a permutational ANOVA (PERMANOVA) add-on package (Primer-E Ltd). Oyster data will be square-root transformed prior to analyses and then a triangular matrix of similarities (Bray-Curtis similarity) will be constructed between each pair of samples.

Non-metric multidimensional scaling (nMDS), an iterative process that uses ranks of similarities, will be utilized to visualize patterns in oyster chemical composition. The significance of year, region, farm, and location of oysters inside or outside of kelp beds on oyster chemical composition will be examined using nested PERMANOVA designs. We will use distance-based linear models (DISTLM) and distance-based redundancy analysis (dbRDA) in FY30-FY31 to understand the impact of both categorical polyculture variables (i.e., region, year, farm, location relative to kelp within farm) as well as continuous environmental variables (i.e., temperature, chl a) in determining the multivariate compositional analysis of oysters from commercial farms.

A similar approach will be taken to understand the impact of oysters on the compositional quality (i.e., organic to inorganic, C:N ratios, proportions of fatty acids) of kelp, except additional continuous water quality variables (i.e., PAR, nutrients) will be used in DISTLM models. Statistical analyses of both morphometrics and compositional quality will be viewed together to give a more holistic understanding of the impacts of polyculture on both kelp and oysters. These approaches will help us determine how both polyculture and regional-scale environmental variability interact to collectively determine oyster and kelp production and product quality. This knowledge can help inform the industry about future locations that may be best suited for scaled-up commercial polyculture production.

Objective 3A.3: Evaluate the spatial and temporal occurrence in contaminants in farmed and wild seaweeds.

Seaweed contaminant results will be compared among the nine farm sites using multivariate linear models. Contaminant levels will be compared with results from other regions.

3B: Oyster Selective Breeding

a) Hypotheses and Objectives

Hypothesis 24. Performance of triploid and diploid oysters will differ from each other and will vary with increased water temperature.

Objective 3B.1: Compare the performance of triploid and diploid oysters in farms in the EVOS spill area.

Rationale: Triploid oysters have three sets of chromosomes instead of the usual two and are advantageous to the oyster aquaculture industry because they do not reproduce, and thus they grow faster than oysters that do reproduce (Guo et al. 2009). Triploids are prevalent in the oyster industry on the US east coast and only more recently have they been utilized in the Pacific Northwest and Southeast Alaska. Pacific oysters (*Crassostrea gigas*) are the only non-native species allowed for aquaculture purposes in Alaska, and to date they have not been able to reproduce because the water has historically been too cold. This triploid technology may be needed to advance development of Alaskan mariculture to ensure that oysters do not reproduce in the wild as waters warm.

Hypothesis 25. Selective breeding will result in oysters with higher growth and survival rates in the EVOS region, compared with currently available seed from Hawaii or the Pacific Northwest.

Objective 3B.2: Develop Alaska-specific Pacific oyster (*Crassostrea gigas*) broodstock for optimized growth in the *Exxon Valdez* oil spill region.

Objective 3B.3: Develop methods for spawning and rearing Pacific oyster larvae that are tailored to conditions in Alaska and are cost effective at scale.

Rationale: The oyster industry is well poised for rapid expansion in the region; however, the lack of oyster hatchery capacity to produce oyster seed in Alaska and oyster strains optimized for growth in the region present significant hurdles for current and future farm operations (Alaska Mariculture Task Force 2018). The 2018 Alaska Mariculture Development Plan identifies the goal to grow a $100 million mariculture industry, a 67-fold increase, in 20 years with the #1 priority to secure seed supply through Alaska hatcheries. To date, Alaska oysters have not been spawned successfully, consistently, and cost-effectively, creating a reliance on larvae supplied from outside the state and an extreme insecurity and shortage of seed supply. Likewise, oyster strains cultivated in Oregon and Hawaii hatcheries have been bred for optimized growth in the Pacific Northwest (De Melo et al. 2018) where the range, seasonality and variability of temperature, pH, tidal amplitude, and salinity regimes in the nearshore differ from those found in the EVOS region (Fassbender et al. 2018, Kelley et al. 2021a). The goal of this component is to resolve the scientific barriers and identify cost efficiencies to producing larvae and seed within Alaska that are optimized for growth in Alaska. Once developed, this technology can then be transferred to the industry.

b) Study Design, Procedural and Scientific Methods

Objective 3B.1: Compare the performance of triploid and diploid oysters in farms in the EVOS spill area.

We will engage five shellfish farmers involved with this program to grow triploid oysters on their farms and compare survival and growth with diploid oysters. Triploid oyster seed will be sourced from Hawaiian Shellfish LLC in FY23 and FY24 and reared on five oyster farms following the methods and gear that each farm uses to rear oysters. Oyster survival and cohort growth (fraction in each size class) will be quantified until oysters reach market size for both diploid and triploid oysters. Oyster shell, meat and gonad wet weights will be recorded annually for 30 triploid and 30 diploid oysters from each farm.

Objective 3B.2: Develop Alaska-specific Pacific oyster (*Crassostrea gigas*) broodstock for optimized growth in the *Exxon Valdez* oil spill region.

Objective 3B.3: Develop methods for spawning and rearing Pacific oyster larvae that are tailored to conditions in Alaska and are cost effective at scale.

Selective breeding efforts on Pacific oysters have successfully resulted in higher yields and lower mortality in farms across the Pacific Northwest, with much of this work being led by the Molluscan Broodstock Program in Oregon (e.g., Langdon et al. 2003, Evans and Langdon 2006, De Melo et al. 2018). We propose to build off of these selective breeding efforts by focusing on the needs of oyster farmers in the EVOS region, which experiences greater seasonality than the Pacific Northwest, including colder sea surface and air temperature, highly seasonal phytoplankton blooms, and lower pH levels, among other environmental parameters known to impact oyster growth (Hollarsmith et al. 2019, Miller and Kelley et al. 2021a). By focusing selective breeding efforts on oysters that grow successfully in the environments found across the EVOS region, we hope to increase production on these farms while also building the expertise and infrastructure necessary to support Alaska-based hatchery operations.

Testing of the oyster strains will occur at current and future oyster farms in Kachemak Bay (Figure 3b) and PWS (Figure 3a). Housing, conditioning, and spawning the broodstock will occur at NOAA facilities in Kodiak or Juneau. Grow-out of the oyster seed to a size appropriate for placement in farms will occur in FLUPSY nurseries based in Alaska. NOAA facilities were chosen for this work because selective breeding is a time- and resource-intensive effort with delayed financial payoff. Considering the small size of the shellfish industry and the limited hatchery facilities present in the state, it would not be cost effective for a hatchery to undertake research and development while also producing seed for multiple species. Likewise, basing the work at NOAA ensures the availability of auxiliary research infrastructure, personnel, and expertise that will be necessary for the project's success. NOAA will pursue a hatchery permit to allow for the holding of live oysters, and regulation changes are also being pursued that would allow research facilities to hold live oysters.

Broodstock Sourcing: Broodstock oysters will be sourced both from Alaska oyster farms, with the majority from farms in the spill area, and from wild-set populations in the Pacific Northwest. This combination will allow us to build on breeding efforts already underway on oyster farms in Alaska while also enhancing the genetic diversity of the founding population to avoid the low effective population sizes of oysters from existing hatcheries (Appleyard and Ward 2006). We will collect 100 oysters from five Alaska oyster farms, with farmers choosing oysters that had high growth from cohorts that had high survival. An additional 100 oysters will be collected from hatcheries in the Salish Sea and Oregon coast that experience frequent low salinity events and highly variable pH environments. All oysters will be shipped to the NOAA Ted Stevens Marine Research Institute in Juneau, AK, where they will be separated into tanks by population, maintained at ambient seawater temperatures, and fed cultured microalgae.

*Spawning and Larval Rearing***:** To initiate spawning, temperatures will be raised and fluctuated between 18 -23°C and oysters will be fed abundant microalgae. Oysters in each tank will be strip-spawned following methods in Langdon et al. (2003) and populations collected from farms will be crossed with wild-set populations to create an F1 generation of 25 full-sib families. Families will be reared through the larval phase at the NOAA facilities until they metamorphose into juvenile oysters, at which time they will be transported to a FLUPSY at an Alaskan oyster farm. Once oysters have grown to a sufficient size to be out planted to the farms (12-20 mm), spat from each family will be shipped to farms in the spill area (Kachemak Bay, PWS, Kodiak Island) for a grow-out period during which farmers will monitor growth and survival of each family. Families will be maintained separately throughout the grow-out period on the farms. Environmental conditions, including temperature, salinity, dissolved oxygen, pH, PAR, and nutrients, will be measured at each farm during the grow-out period, allowing us to assess interactions between water column parameters and oyster families.

Subsequent Generations: Farmers will determine survival rates of each F1 family annually. Ten F1 families with the highest survival rates will be selected for continued breeding. Farmers will collect 10 oysters from each of the selected F1 families, targeting oysters that grew largest during the grow-out period, and ship these oysters to the NOAA facilities. Following the methods for the creation of the F1 families, the best performing oysters in F1 will be crossed to create 25 F2 generation families. Spat will be sent first to the FLUPSY, and then to farmers. This process will repeat for the duration of the EVOS proposal, with the ultimate goal being the establishment of one or more strains that perform well across the entire EVOS region and have been sufficiently crossed to maintain genetic diversity.

Production Metrics: Oysters will be evaluated for growth rates, mortality, and tissue composition between generations, families, and oceanographic conditions to assess productivity. Quarterly, 20 oysters from each generation within each farm site will be randomly selected and shipped on ice to the NOAA facilities and the whole organism will be weighed (shell and internal organs) and then each will be weighed individually. Shell and tissue will be preserved in 70% ETOH for later analyses of shell composition and gene expression in FY29-FY31. Farmers will track mortality in each oyster rack, composed of one full-sib cohort. Survival rates will be determined annually by calculating the final number of oysters minus the initial number of oysters in a rack. Fatty acid profiles will be generated for individuals from each cohort to determine the relative food quality from site to site. These analyses will be performed in conjunction with Component 1.

Physiological assays for shell composition, genetic diversity, and metabolic rate will occur in FY29-FY30 after five years of selective breeding. Analyses will include oysters sourced from hatcheries in the Salish Sea and Oregon, and oysters sourced from seed purchased from hatcheries in Oregon, Washington, and Hawaii and grown on Alaska farms.

Depending on the relative availability of the carbonate ion in seawater, shell composition can vary widely among marine mollusks as other ions are incorporated into the shell matrix when the carbonate ion is limited. Individual oyster shells from each cohort will be imaged using an environmental scanning electron microscope (ESEM) equipped with SSD Energy Dispersive X-ray Spectroscopy to quantify elemental composition of each shell (Jacob et al. 2008). Comparisons of elemental composition between cohorts and across sites can be used to infer the relative role the environment plays in determining the elemental constituency of bivalve shells.

To assess genetic diversity, gene expression profiles will be characterized for individuals in each cohort from gill tissue samples. The genome of *M. gigas* has been sequenced (Peñaloza et al. 2020, Yin et al., 2020) providing a rich resource from which gene-specific primers can be synthesized. Previous studies have identified genes associated with fast growth in *M. gigas* (Meyer and Manahan 2010) which can be used as biomarkers of performance in our respective breeding cohorts. Using qPCR, gene expression of the following genes will be quantified: 1) *SCPb*, a small cardioactive neuropeptide which regulates muscle contraction in molluscs and is noted for its roles in gut motility and radula activity. *SCPb* expression was only detected in the slow growing oyster line. 2) ATP synthase is a key component in cellular metabolism, converting ADP and phosphate to ATP, the currency for cellular energy. The expression of this gene can be used as a means to better understand cellular metabolism. 3) peptidylprolyl isomerase, a gene that increases the efficiency of protein folding and was significantly upregulated in fast growing oysters. Quantitative real time PCR methods for measuring gene expression will follow the approach outlined in Hofmann et al. (2008).

Standard metabolic rate (MO_2) will be measured on individual oysters from each cohort across the study period. Individuals will be placed in BOD containers outfitted with a fiber optic oxygen spot sensor. Oxygen concentration will be measured hourly using PreSens OXY-4 SMA 4-channel fiber optic oxygen transmitter over the 12-hour period. Throughout the respirometry trials, a threshold of 80% O_2 saturation will not be breached to ensure that no additional physiological stress occurs due to low oxygen concentration (Jones et al. 2021).

c) Data Analysis (If Applicable), Statistical Methods (If Applicable) and Measuring Project Success

Objective 3B.1: Compare the performance of triploid and diploid oysters in farms in the EVOS spill area.

The goal of the analyses will be to determine differences in oyster morphometrics and physiology among generations and across farm sites over the course of the breeding experiment to determine changes in the oysters due to breeding as well as the influence of oceanographic context of the farm on these morphometrics. Oyster survival, oyster growth, and shell, meat and gonad indices will be compared between triploid and diploid oysters using linear models that treat each of the five farms as blocks and temperature (degree days between time points) as a covariate.

Objective 3B.2: Develop Alaska-specific Pacific oyster (*Crassostrea gigas*) broodstock for optimized growth in the *Exxon Valdez* oil spill region.

Objective 3B.3: Develop methods for spawning and rearing Pacific oyster larvae that are tailored to conditions in Alaska and are cost effective at scale.

Early juvenile and adult weight and shell length and width data collected quarterly will be used as model inputs for a simple exponential growth model (EGM) to estimate the growth rate of each generation of *M. gigas*. The applied, projected, model is: $SA_t = SA_0\, e^{rt}$, where SA_t = is the shell area (length x width, mm, measured with digital calipers) at time t, SA_0 = is the initial shell area prior to outplanting, and r is the instantaneous growth rate (mm d^{-1}). Additionally, to understand the influence of temperature (degree day influence) and salinity on the absolute and allometric growth rate of oysters regionally, we will use a mathematical model that integrates temperature and salinity as model inputs following Brown &

Hartwick (1988). The relationship of whole organism metabolism or shell composition and generation and source population will be assessed using generalized linear models. All physiological statistical analyses will be conducted using R (v 4.0.3) with the R Studio user interface (v 1.3). α level will be set at $p < 0.05$ for all analyses.

Growth rates, as calculated above, and survival rates will be compared across sites and generations using generalized linear models, including an interaction term of site and generation. Survival rates will be calculated by comparing the number of oysters alive at the time of outplanting onto the farm with the number alive after one and two years on the farm, with oyster rack being the unit of replication. As the breeding progresses, year will also be included in analyses to determine whether growth rates are increasing with selective breeding. The relationship between growth and survival rates and oceanographic context will also be assessed using the same analytical methods outlined in Component 1. Namely, site environmental conditions will be assessed using principal components analysis, including seasonal mean, highest 2.5%, and lowest 2.5% (2 standard deviations) values of temperature, salinity, dissolved oxygen, nutrients, and PAR at each farm site. The first and second principal components for each site will then be used as predictor variables in another set of generalized linear models comparing growth and survival rates with environmental context. To determine whether differences in physiological parameters (metabolism, gene expression, etc.) exist between families and sites, a general linear model will be used with family, and site as factors.

3C: Kelp Farming Method Development

a) Hypotheses and Objectives

Hypothesis 26. Reductions in cultivated kelp yield are driven by competition for light, nutrients limitation, or an interaction of both; hence either increasing spacing in between lines or reducing seeding densities will optimize yields across kelp farms.

Objective 3C.1: Apply and refine existing seeding approaches to optimize yields across kelp farms.

Rationale: To date, kelp farming parameters in the United States are based on the Ocean Approved Kelp Culture Manual (Flavin et al. 2013) and Bull Kelp Cultivation Handbook (Merrill and Gillingham 1991). The effectiveness of the current seeding densities and farm setups is linked, to some extent, to the relatively small farm sizes operating to date and prevailing environmental conditions at site. It is likely that as kelp farms increase in scale, new challenges will arise. Mariculture experience in China has shown that seeding kelp farms at suboptimal higher densities (per line and area) tend to result in overall low yields, particularly lower towards the farm's inner sections. They also report that plants tend to show less vigor and growth and increased signs of disease, with these outcomes becoming more visible as farms grow larger (Shi et al. 2013, Fang et al. 2016). Similar to what has been reported in China, yields from an experimental farm of sugar kelp installed off Kodiak Island, AK, decreased as the spacing between grow-out lines decreased (Stekoll, pers. comm.).

Hypothesis 27. Pre-harvest trimming of distal-end portions of blades will increase farm yields by allowing a greater amount of wet weight biomass to be harvested by unit area.

Objective 3C.2: Determine the effect of early season trimming on kelp.

Rationale: Pre-harvest trimming of blades may be a strategy to increase kelp production and revenue per farming season. In northern China, pre-harvest trimming of blades has improved the performance of farmed *Saccharina japonica*, by increasing light and nutrient availability within kelp rows (Tseng 1962). Similar results have been reported in South Africa, where multiple trimming of the kelp *Ecklonia maxima* increased yield per unit effort (Levitt et al. 2002).

Hypothesis 28. Kelp specimens will show different tolerance limits based on their ecotype, with juvenile kelp derived from warmer and less saline regions showing a broader tolerance range.

Objective 3C.3: Determine the temperature and salinity limits of juvenile kelp sourced from parent stocks from different regions.

Rationale: Environmental conditions, directly and indirectly, influence seaweed distributional patterns and performance at different scales (Breeman 1988, Harley 2012). Changes in environmental conditions, for example, because of heatwaves and freshwater input, will result in changes in farms' performance. A recent study exploring the resiliency of early life history stages of four kelp species in Alaska found differences in spore settlement and gametophyte development due to differences in temperature and salinity. The study did not provide evidence related to the absolute tolerance limits of any species at the juvenile stage, critical to kelp farming. It is the stage at which seeded spools are deployed at sea at the beginning of the farming season.

b) Study Design, Procedural and Scientific Methods

Objective 3C.1: Apply and refine existing seeding approaches to optimize yields across kelp farms.

Farms will be divided into quadrants for sample and data collection. Quadrants will be assigned a number used to locate from where samples and data are collected. Water samples to measure dissolved inorganic nitrogen and measurements of light penetration into the water column will be collected from every quadrant. Ten plants from each quadrant will be collected to obtain morphometrics of maximum blade length, width, thickness, and maximum stipe length and diameter. We will also collect tissue samples for carbon and nitrogen analysis using NETs© (Nutrient bioextraction toolkits). On the same week of harvest, up to five plants randomly selected per quadrant will be used to obtain rapid light curves using a diving PAM fluorometer (Ralph and Gademannon 2005). Both morphometric and photosynthetic traits will be used to assess blade responses to potential changes in light and nutrient availability. An estimate of farm yield (total biomass per area) will be obtained by weighting all biomass (wet weight) in 50 cm segments (one segment per quadrant). Assessments will be conducted for sugar kelp, *Saccharina latissima*, and winged or ribbon kelp, *Alaria marginata* in FY23 and FY24.

Once reference values have been obtained for both species, we will modify the seeding density and spacing within grow-out lines. Kelp will be seeded at two different densities so that each density differs from the other by one order of magnitude (i.e., 500, 5000 -current seeding density) to test the effect on density in yield. The distance of grow-out ropes at deployment will be that of the farm setup used to obtain the baseline values described above. On a parallel assessment, kelp will be seeded at 5000 per ml and deployed in grow-out lines separated by different distances (i.e., the usual distance at site vs. double that distance). These setups will allow measuring differences in kelp performance as a function of space in between grow-out lines. The same morphometrics traits, elemental composition, and yield estimates described above will be measured. Assessments of the effect of seeding density and distance in between grow-out lines will start with sugar kelp in FY23 and FY24 and followed by winged kelp assessments in FY27 and FY28. The lag in between will allow data processing and analysis and measurements of other parameters and responses (3C.3).

Objective 3C.2: Determine the effect of early season trimming on kelp.

Trimming treatments will be conducted for two consecutive farming seasons, three months before harvest. The experimental farm will be divided into sections that will either be trimmed to 1 m in length, starting at the junction of the blade and stipe (Figure 8) or not. Trimmed biomass will be weighed to obtain total wet weight biomass. Approximately, 10 g of tissue will be stored for further analysis such as C and N determinations, while the rest will be returned to the farmer who will process it as desired.

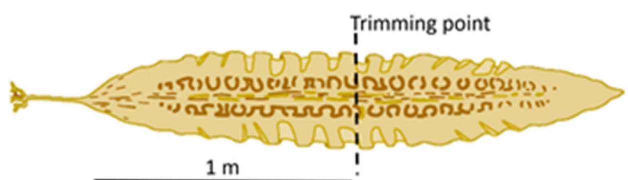


Figure 8. Schematic of distal-end trimming in a blade.

Water sampling and light measurements will be conducted monthly 30 days after deployment on the farm. Values will be used as a reference to assess differences in kelp performance. At harvest, 30 blades per section (trimmed vs. untrimmed) will be collected and processed to obtain blade traits and elemental composition measurements as described above. Yield for untrimmed blades will be estimated as wet weight per area by weighing all biomass from five-50 cm of seeded rope per farm section. Changes in kelp's photosynthetic activity right before and right after trimming will be assessed by generating rapid light curves for up to 15 blades using a diving PAM (Ralph and Gademannon 2005). Assessments of the effect of pre-harvest trimming on the performance of kelp will be conducted in FY25 and FY26 for sugar kelp and in FY29 and FY30 for winged kelp. Similar to 3C.1, the lag in between will allow data processing and analysis and measurements of other parameters and responses (3C.3).

Objective 3C.3: Determine the temperature and salinity limits of juvenile kelp sourced from parent stocks from different regions.

Fertile blade tissue of sugar kelp and winged kelp (n= 3) will be collected from one population within the designated geographical area. Meiospores will be obtained following standard spore release procedures for Laminarians (Flavin et al. 2013). After meiospore germination, gametophytes will be sexed to obtain two females and two males per geographical area and isolated to individual Petri dishes containing enriched seawater plus germanium dioxide, GeO_2 to avoid diatoms. Biomass fragmentation will be conducted for 15 consecutive months or until 1 g of biomass is produced. After that, cultures will be moved to dormant conditions until use. One female and male uniclonal culture per geographical area will be selected for cross-fertilization to obtain sporophyte clones. The availability of clones will eliminate variability driven by genetic predisposition or enhancements. The experimental design will consist of serial assessments conducted in 30-day intervals. Clones of 3 mm in length will first be subject to single factor treatments of salinity and temperature. Single-factor assessments will allow increasing the experimental ranges and reducing the intervals of each treatment. Once the maximum and minimum limits are obtained, we will conduct full factorial assessments consisting of three salinities and temperature treatments to measure their interactive effect in kelp development.

c) Data Analysis (If Applicable), Statistical Methods (If Applicable) and Measuring Project Success

Objective 3C.1: Apply and refine existing seeding approaches to optimize yields across kelp farms.

These analyses will examine how seeding density and the use of space in a kelp farm affect light and nutrient availability in different farm sections. They will also allow detecting whether and how kelp's photosynthetic activity varies due to potential changes in light and nutrient availability, thus affecting yield. Correlation matrices and boxplots will explore relationships between quadrant location within the farm, light and nutrient availability, and morphometric and composition traits and quadrants. All photosynthetic parameters will be analyzed using BIOENVs procedures (Clarke and Ainsworth 1993) in Primer 7 (Clarke and Gorley 2015) to visualize correlations between biological and environmental parameters (see Umanzor et al. 2020 as a reference). Statistical differences in photosynthetic activity will be analyzed using ANOVAs and post hoc comparisons.

Objective 3C.2: Determine the effect of early season trimming on kelp.

These analyses will explain how pre-harvest trimming of blade distal ends affect light and nutrient availability within a farm and if trimming could result in increased farm yields. Histograms will help to visualize the distribution of trait measurements in trimmed vs. untrimmed samples. Correlation matrices will show correlations between yield, light, nutrients, and trimming treatments. Statistical differences in light, nutrient, and temperature will be analyzed using ANOVAs and post hoc comparisons. Measurements of photosynthetic activity derived from rapid light curves will be explored as described before.

Objective 3C.3: Determine the temperature and salinity limits of juvenile kelp sourced from parent stocks from different regions.

These analyses will provide statistical evidence of the effect of salinity, temperature, and their interactions in growth rates and photosynthetic activity of juvenile sporophytes of kelp. A full two-way factorial ANOVA by least mean squares and post hoc comparisons will be used to examine the interactive effects of the salinity and temperature on the performance of juvenile sporophytes.

COMPONENT 4: Economic Feasibility Analysis

a) Hypotheses and Objectives

Hypothesis 29. Commercially producing oyster seed in the EVOS affected region and other locations in Alaska will be economically competitive and necessary for the industry to scale up in Alaska.

Objective 4.1: Develop a stochastic model of commercial oyster hatcheries in the EVOS region and other regions that quantifies regional variability in the costs of hatchery establishment and operation, including the cost of broodstock, the type of growing system, and labor costs.

Objective 4.2: Use the stochastic model to assess under what conditions Alaska-produced oyster seed are competitive to the current sources of oyster seed imported from other states.

Hypothesis 30. Growth of the oyster industry will increase with improved marketing and will be impacted by production levels at existing farms, number and size of new farms, and perception about industry growth.

Objective 4.3: Collect marketing data and information such as user preferences of Alaska oysters, buying patterns such as seasonal trends, and prices.

Objective 4.4: Develop a projection of the growth of demand of oyster seed in Alaska over the next 20 years, based on factors such as increased production at existing farms, number and size of new approved farms, number, and size of farm applications under review, and assumed continued growth of the industry.

Rationale: Oyster farms require nursery operations to purchase seed from in order to replenish stock as oysters are sold. Oyster seed can be difficult to acquire as no local seed source is available in Alaska. Farmers rely on commercial hatchery seed sales from out of state, and except for one or two operations (e.g., Whiskey Creek Hatchery), oyster hatcheries are owned by existing vertically integrated farms. This arrangement is suboptimal to Alaska farmers. Vertically integrated farms that own oyster hatcheries prioritize their own operations first. If, for some reason, the vertically integrated farms have a substantial increase in the demand for seed, they will allocate their seed internally and will not sell to the public. Similarly, if a vertically integrated oyster hatchery (business is integral to a farming operation), has an off cycle of production resulting in suboptimal level of production due to unforeseen circumstances such as ocean acidification or diseases, seed produced will be prioritized to supply internally.

Recognizing this uncertainty, the Alaska Mariculture Task Force recommended in the Alaska Mariculture Development Plan (Alaska Mariculture Task Force 2018) that the number one priority to support growth of the mariculture industry in Alaska is to "**Secure seed supply, of existing seed types, oyster and geoduck"** with the following specific recommendations:

- Improve quantity of in-state production of oyster and geoduck seed
- Improved quality of the seed available to farmers in Alaska
- Secure Alaska broodstock
- Selective breeding of Pacific oysters, regionally specific to different areas of Alaska
- Diversification of species, develop sources of seed for native shellfish species
- Establish hatchery, nursery, and grow-out techniques for rearing shellfish species with current or emerging potential for private, public, and Tribal shellfish mariculture, enhancement, restoration, and mitigation.

Moreover, the recommendations from the Alaska Mariculture Task Force's Research and Development Advisory Committee in June 2017 stated that high priority should be placed in conducting an economic feasibility analysis of an Alaska based shellfish hatchery (Alaska Mariculture Task Force 2018). While the establishment of an oyster hatchery is a near term priority to Alaska, as new species are considered as candidates for mariculture, hatchery development will also be a critical component of the supply chain to ensure consistent availability of quality seed to the industry. Work by Alaska Sea Grant is already ongoing to assess the economic feasibility of kelp hatcheries in Alaska.

The overall goal of this work is to conduct an economic feasibility analysis of a shellfish hatchery, specifically an oyster hatchery in Alaska, to determine what components are needed to produce economically viable oyster seed. A shellfish economic feasibility analysis template will be developed through this project and the PI leads for the economic component will be seeking additional funding, outside of this call, to look at another shellfish species (i.e., sea cucumbers, sea urchins). An advisory committee from the mariculture industry and academia will be formed to advise all aspects of the analysis and will determine which species to be part of the economic analysis after the completion of the oyster hatchery analysis cycle. It is also envisioned that the committee will advise the researchers in hatchery design, data sources, and other pertinent resources to guide the successful completion of the project.

b) Study Design, Procedural and Scientific Methods

Objective 4.1: Develop a stochastic model of commercial oyster hatcheries in the EVOS region and other regions that quantifies regional variability in the costs of hatchery establishment and operation, including the cost of broodstock, the type of growing system, and labor costs.

Objective 4.2: Use the stochastic model to assess under what conditions Alaska-produced oyster seed are competitive to the current sources of oyster seed imported from other states.

The feasibility of establishing a commercial oyster hatchery will not only depend on the continuous development and refinement of culture techniques, but also on estimated market demand, product price, and cost of production. Cost of production, together with market price, can determine if the expected profit will provide an adequate return to labor, management, capital, and risk. =Existing and prospective investors, policy makers, and the Alaska oyster farming industry can have answers to the following questions:

- What will it cost to raise the oyster seed to market size?
- For what price can the oyster seed be sold to provide an adequate return?
- What is the break-even price for culturing oyster seed?
- What is the optimal size of a commercial oyster hatchery production facility to supply current and future needs in Alaska, with the possibility of exporting to other states?

In addition to answering these questions, understanding costs of production can also allow us to perform sensitivity analysis on key production parameters so as to identify potentially vulnerable areas which planners can build in risk mitigation strategies in a hatchery business and operational plan. This proposed work will evaluate the economic feasibility of a potential oyster hatchery production system based on the operational experience of two research/non-profit hatcheries in Alaska, expert opinion from for–profit and research oyster hatcheries in the U.S., and existing literature. Furthermore, it is important to appraise the product price sensitivity of the operations since farm-gate prices might be depressed with increased production.

In order to conduct a realistic cost and return feasibility study on a commercial oyster hatchery, the design of the facility needs to incorporate the appropriate equipment and space, and realistic operational parameters such as production capacity, survival rates, energy and water use, microalgae production as oyster food, and the optimal number of personnel with appropriate expertise etc. that are required. Aside from the advisory committee, we will approach in- state and out-of-state expertise to assist. The team will contact Jeff Hetrick, the current hatchery manager from Alutiiq Pride Shellfish Hatchery; Connor Eckholm, former hatchery manager, Oceans Alaska; and Trevor Sande and Eric Wyatt, oyster farmers/nursery operators, to gather information on operational parameters in Alaska. The team will also approach oyster hatchery experts both from the public and private sector. These experts may include Sue Cudd, Whisky Creek Hatchery; Maria Haws, Pacific Aquaculture and Coastal Resource

Center, University of Hawaii Hilo; and Stuart Thomas, Farm Manager, Swinomish Shellfish Company (former Hatchery Manager, Taylor Shellfish), for their expert opinion on the design of an "optimal" commercial oyster hatchery. Cost data will be collected through contacting vendors, utility providers, and contractors. The mentioned process is similar to what is already being done with kelp hatcheries and will be applied to subsequent hatchery feasibility analyses for species as determined by the advisory committee.

Production costs will be developed based on the operating parameters of the conceptual commercial oyster hatchery operations with varying sizes and operating systems in Alaska. The team will review existing literature, interview oyster hatchery experts, and will collect all the necessary information to construct prototype enterprise budgets. Capital costs, overhead expenses, and variable operating costs will be estimated using the current costs faced by the non-profit and research hatchery in Alaska. Cost data for hatcheries that are not yet operations in Alaska will be collected from equipment suppliers and contractors. A stochastic modeling system will be developed consisting of an integrative performance evaluation module supported by several bio-techno-economic sub-models detailing the oyster culturing operations. This approach is based on previous work by Chen et al. (2017), Fong et al. (2005), Leung and Moss (1999), Moss and Leung (2006), Kam et al. (2002), Yu and Leung (2005, 2006) and Zucker and Anderson (1999). This integrative performance evaluation module integrates the physical, biological, and market sub-modules to generate the bottom-line financial outlook of the entire operation using a discounted cash flow analysis. Specifically, it will combine costs and revenues from the information obtained to calculate the net present value of returns and the uncertainty (standard deviation) over a twenty-year period. The modeling system will be implemented as a Microsoft Excel© spreadsheet. Incorporating risk and uncertainty will be achieved by using the spreadsheet add-in Risk Solver Platform© to assess the effects of many of the not-so-sure production, market, and cost parameters. Monte Carlo simulation procedures will be used to generate an entire range of possible outcomes and the probability of achieving them. Different scenarios will then be used to determine the "best" outlook for the financial health of a commercial oyster hatchery operation in Alaska.

Objective 4.3: Collect marketing data and information such as user preferences of Alaska oysters, buying patterns such as seasonal trends, and prices.

Objective 4.4: Develop a projection of the growth of demand of oyster seed in Alaska over the next 20 years, based on factors such as increased production at existing farms, number and size of new approved farms, number, and size of farm applications under review, and assumed continued growth of the industry.

A goal of this study is to determine the specifications of current and future seed products in Alaska. The problem setting for this part of the research is the utilization and market preferences for oyster seed. Some of the questions that address this problem setting are: what are the current and projected product characteristics such as size that end-users prefer? What is the current and future structure of the supply chain for these products? What is and will be the current pricing structure for seed for oysters? Would buyers pay a premium for locally produced seed? What is the future demand for seed in

Alaska? How do users assess seed product quality? These are some of the attributes that will be incorporated into the production model for the economic feasibility analysis.

Executive interviews will be conducted with Alaska farmers about their preferences and opinions regarding oyster seed products, as well as their experiences. The executive interviews will be conducted until "theoretical saturation" is reached. At the point of theoretical saturation each additional conversation with a farmer contributes few or no new insights to the researchers' understanding of the topic (e.g., Aaker et al. 2012, Maholtra 2008). From the results of executive interviews, an "ideal" oyster seed favored by Alaska oyster farmers can be identified. This "ideal" oyster seed will then be used as the basis for the economic feasibility analysis for the oyster hatchery production system (e.g., Aaker et al. 2012, Maholtra 2008).

A projection of the growth of demand of oyster seed in Alaska over a 20-year horizon will be necessary and will be based on factors such as increased production at existing oyster farms, number and size of new approved farms, number, and size of farm applications under review, and assumed continued growth of the industry. The proposed market research activities will also be applied to existing and potential oyster farmers on the West Coast of the U.S. recognizing that in the short run, developing an oyster hatchery in Alaska may not be justified due to low seed demand in Alaska. Selling outside the state during startup may be the only option to keep the hatchery solvent. The result of the out-of-state market analysis would also be incorporated into the feasibility study (e.g., Aaker et al. 2012, Maholtra 2008).

COMPONENT 5: Product Development

a) Objectives

Objective 5.1: Develop industry-driven proof-of-concept product forms for seaweed and shellfish that consumers may favor through five 2-year product development cycles over the 10-year research period. If successful, seaweed and shellfish prototype products will be adopted by industry to be further developed for large-scale commercial production.

Rationale: Food science is a critical component of any industry involving developing products for human consumption. Mariculture is no different. Product development and food safety allow us to make the best food available given our resources with minimal waste. How harvested (both wild and cultivated) resources act during harvesting, processing, distribution, storage, and preparation is a complex problem and requires trained professionals that are aware of all aspects of the process to develop food safely. Further expansion of the mariculture industry is limited by the threat of contaminants and pathogens, by competition for market niches both domestically and internationally, and by lack of consumer preferred products. The development of novel food products and working with emerging businesses who are developing items for human consumption needs to be done using methods that avoid health hazards during handling, preparation, and storage.

Sustainable economic viability of a mariculture operation depends on efficient coordination of the entire value chain. Inefficient processing may drive up product cost, creating a high-priced product that cannot compete in the marketplace. A logistic chain that is not well developed may result in loss of product quality, resulting in disposal or non-acceptance, creating loss to the seller. Ultimately, it is the consumer that determines the success of a producer because the consumer is who decides how much they are willing to pay and what volume they would purchase based on their needs and wants (e.g., Guiné et. al. 2020).

Recognizing the importance of markets, the Alaska Mariculture Development Plan (Alaska Mariculture Task Force 2018) stated the need to engage in "research and development of new product forms and new market opportunities…", and made recommendations on developing frozen oysters and mussels, and the need for seaweed product and market development in domestic and international markets. Indeed, Covid-19 has negatively impacted Alaska's oyster farming industry, due to closures of many food service companies, upon which the industry was almost entirely reliant for selling oysters, resulting in dramatically reduced oyster sales. If Alaska oyster farmers had diversified into other value-added products, such as frozen oysters, farmers could have more easily pivoted and sold the same production, if not more, as frozen into retail markets, which experienced dramatically increased sales during the pandemic. Product and market diversification is essential for stability and growth for any food producer.

Seaweed farmers also face a lack of market demand. Seaweed farms in Alaska are producing below capacity or sitting idle. This can be attributed to consumers who are not aware of or familiar with domestically produced seaweed and may not associate with its uses beyond the familiar Asian cuisine (e.g., sushi rolls, Japanese or Chinese seaweed salad, etc.). The expansion of the Alaska seaweed industry into the domestic and European markets hinges upon the development of new seaweed products that these consumers can recognize and that meets their preferences. This project will work with industry members to ensure products developed meet market demands, are safe from foodborne illnesses, and follow rigorous scientific methods for development and safety.

b) Study Design, Procedural and Scientific Methods

Objective 5.1: Develop industry-driven proof-of-concept product forms for seaweed and shellfish that consumers may favor through five 2-year product development cycles over the 10-year research period. If successful, seaweed and shellfish prototype products will be adopted by industry to be further developed for large-scale commercial production.

The development of seaweed and shellfish prototype products will contain the following phases for each product development cycle:

1. Create an Advisory Committee to guide activities in an iterative process, consisting of members from both industry and academia; conduct comprehensive literature review.
2. Conduct focus group interviews to identify product attributes that end users favor.
3. Manufacture selected prototypes.
4. Conduct targeted consumer surveys from a large sample to assess the feasibility of prototypes in the marketplace.
5. Dissemination of results by webinars, outreach to industry, and through extension and peer reviewed publications, and the provision of one-on-one consultation services by Alaska Sea Grant's Food Technologist to facilitate manufacturing process adoption.

This work will be supported in this EVOS proposal with a postdoctoral researcher, who will be supervised by Quentin Fong and Chris Sannito. Chris Sannito is externally funded through the Alaska Manufacturing Extension Partnership Center. Melissa Good will serve as a liaison to the mariculture industry in the spill area. The methods adopted for this work follow well-established market research and food product development procedures by engaging in all segments of industry to gather preliminary information, use of focus groups to define product attributes, involving consumer taste or user panels and surveys, employing rigorous data analysis and reporting results (e.g., Blankenship 1998, Earle et al. 2001, Malhotra 2009, Sukkhown 2019).

Phase 1. Engagement, Secondary Information Sources and Advisory Committee: An Advisory Committee, consisting of members from both industry and academia including seaweed processors, seafood processors, aquatic farmers, the Alaska Seafood Marketing Institute (ASMI), and retail markets, will be established to advise on all phases of the study and will be engaged in an iterative process. The Advisory Committee will ensure that products developed show promise in the marketplace, could be manufactured realistically in large volume, and that the research methodology stands up to scientific rigor. It is envisioned that the advisory committee will guide all aspects of product development including species, product forms, and whether the prototype product development should be extended to another product development cycle. We will conduct comprehensive literature reviews of both peer reviewed and non-peer reviewed publications as well as engage professionals from all levels of the food and seafood value-adding chain to develop greater understanding of how farmed seaweed and shellfish contribute to the profitability of their businesses. Results of market studies on seaweed and farmed shellfish, current and future (e.g., AFDF, Maine Aquaculture Innovation Center, Island Institute) will also be reviewed to help guide the formulation of product concepts.

Phase 2. Conduct Focus Groups and/or Expert to Define Product Attributes and Survey Design: We will first engage with the Advisory Committee to seek guidance on the types of products that may be viable. Once guidance is given, the co-PIs will put together a prototype development and testing protocol, with the appropriate experimental design. This will be presented to the advisory group for approval. Upon approval by the advisory committee, focus groups of users will be conducted to gain insights of how the products will be used in the case of food service institutions or value-adding food processors, or how it would be consumed if the product will be designed for direct-to-consumer sales. Further, desired product features such as form, packaging, and other market information such as brand attitudes, willingness to pay, and logistical requirements will also be obtained. The results of the focus group will be presented to the Advisory Committee for the next phase, proof-of-concept product testing (e.g., Kotler and Keller 2015).

Phases 3 and 4. Consumer Taste Panels and/or Value Chain Intermediary Product Evaluation: After the first cohort of promising seaweed and oyster prototypes are identified from focus group interviews, we will formulate the prototype product at the University of Alaska Fairbanks' Kodiak Seafood and Marine Science Center, where we have the only food processing pilot plant in Alaska, with equipment for commercial scale food product development. The facility is also equipped with a test kitchen and experimental taste testing room that can conduct sensory evaluation of food products. Each prototype, if chosen to be a retail product, will be subjected to consumer taste tests. If the product is designed for further value-adding, such as a blanched seaweed frozen product sliced into ribbons with a certain width to be incorporated into a mixed seafood salad, or a frozen shucked oyster shooter, this would be prepared and be mailed to the potential end user, such as research and development departments of ready to eat food manufacturers, or executive chefs who oversee recipe and/or menu development of food service establishments to be evaluated. Responses will be solicited with the use of a survey and analyzed with an Advisory Committee-approved statistical method such as analysis of variance, multivariate discrete –choice regression analysis etc. (e.g., Earle et al. 2001, Hoppert 2012, Yu 2018).

Phase 5. Dissemination of Results and Outreach Activities: The outcomes and recommendations of this proposed work will be presented to stakeholders such as seaweed and shellfish farmers, seafood processors, and seafood value-adding entrepreneurs through webinars. Extension publications will also be developed for broad distribution to the public, and peer-reviewed articles will be published in appropriate scientific journals.

PROGRAM MANAGEMENT COMPONENTS (6-8)

Overall Objective: Ensure the smooth function of interrelated aspects of this project including engagement of diverse stakeholders (e.g., farmers, regulators, funders, product developers, the general public), effective fiscal administration, coordination of project team members, completion of program reporting requirements, and data management.

COMPONENT 6: Outreach

We plan to coordinate many outreach and education activities with the proposed Community Organized Restoration and Learning (CORaL) Network to make current scientific information and activities publicly accessible and serve ongoing, community-identified needs. Here we describe outreach activities that pertain to the mariculture industry specifically.

a) Objectives

Objective 6.1: Outreach to shellfish mariculture stakeholders to communicate the findings of Farm and Business Development Components (3-5) to ensure that the findings of this study are understood by all relevant stakeholders and applied as guidance to industry development.

Objective 6.2: Technology Transfer: Mechanisms and support to share knowledge and experience in the mariculture industry.

Rationale: The mariculture industry in Alaska is small and young. In order for this industry to grow, it is vital to provide training, access to information, and opportunities for knowledge sharing. The Alaska Shellfish Growers Association at their January 2021 meeting identified this as one of their top research priorities.

Objective 6.3: Increase social license of mariculture in the spill area.

Rationale: Past efforts at kelp farming in the United States in the 1970s to 1990s did not materialize into commercial endeavors, and one of the most important lessons learned from a retrospective study indicates that public support is essential for success. “Communications with, and support from, the public are key to receiving a social license for the success of seaweed aquaculture in the United States” (Kim et al. 2019).

Objective 6.4: Host regulatory and management workshops.

Rationale: As shellfish and seaweed farming grow throughout the US, individual states have very different approaches to regulating and managing these industries. We plan to bring together scientists, regulators, and managers in Alaska with scientists, regulators and managers from other states to better understand how different states are successfully supporting growth of these industries as well as protecting common property resources, addressing environmental concerns, and avoiding conflict with diverse user groups.

b) Study Design, Procedural and Scientific Methods

Objective 6.1: Outreach to shellfish mariculture stakeholders to communicate the findings of Farm and Business Development Components (3-5) to ensure that the findings of this study are understood by all relevant stakeholders and applied as guidance to industry development.

The intent of this work is to provide critical information to guide industry development so that the fledgling industry avoids mistakes and expedites development to become viable as soon as possible. Hence, outreach to all stakeholders (farmers, extension agents, policy makers) is key to making these findings useful. The research components (1-3) will be conducted in a participatory fashion so farmers will be engaged and learn by doing. Outreach sessions will be held on a regular basis to update participants on the research progress and findings. Workshops will be held to present findings to the stakeholders to inform industry development. An extension publication and the Excel worksheet that includes the analyses will also be made public for potential lenders/investors and stakeholders to be used as a decision tool. A peer reviewed publication will also be submitted to Aquaculture Economics and Management, a highly regarded peer-reviewed journal.

The researchers from this project will be working closely with our industry and farm partners to identify a pathway in hatchery financing as part of project outreach. Since the proposed work is designed to engage stakeholders, industry experts in all phases of the research process, the advisory committee will be asked to help researchers conduct outreach to potential funders/financiers of proposed hatcheries at the onset of the research cycle. If deemed appropriate, potential funders may be asked to be on the advisory committee. The Alaska legislature will also be informed of this project and be given regular updates to the progress of the project, either through industry organizations such as the Alaska Mariculture Alliance, the Alaska Shellfish Growers Association and/or Alaska Sea Grant. Financing strategy sessions will be conducted regularly either through scheduled regular Alaska Mariculture Alliance or Alaska Shellfish Growers Association meetings, or specific designated meetings. Working closely with stakeholders, the project leads, Fong and Good will also develop a set of pamphlets/briefs, prospectus, and presentations to be distributed and presented to funders in short notices.

At the completion of the project, the PIs, in conjunction with the mariculture industry, will contact the Alaska legislature, potential lenders such as banks, federal agencies such as USDA, and Alaska state loan programs such as Alaska Department of Economic Development Mariculture Loan program, and private equity to determine interests and/or terms for financing. Discussion will also be generated among the industry to determine interest in cooperative formation to finance and operate hatcheries. It is envisioned that formal presentations will be made to possible funders, and prospectus will be distributed to generate interest. Outcomes of meetings will be recorded and summarized as updates to the industry. Recommendations will be included in the final report.

Although the project has a defined start and finish date, the PIs of this project have extension appointments and will continue to work with the industry to work towards fulfilling industry goals of establishing Alaska based hatcheries. This work is the foundation of a long-term effort.

Objective 6.2: Technology Transfer: Mechanisms and support to share knowledge and experience in the mariculture industry.

Technology transfer will be supported by a variety of activities.

Farm site visits: Melissa Good (Alaska Sea Grant mariculture specialist), an expert farmer (who will be compensated for their time), the postdoc who is leading farm coordination, and other scientists will visit active mariculture farms in the EVOS-affected area during coordinated farm site visits to learn about farm activities, share research results with farmers, and to support researcher farmers in farm-based scientific data collection activities.

Creating an information clearinghouse for Alaska farmers: We will create an information clearinghouse that compiles and makes accessible existing global research on shellfish and seaweed that is relevant to

Alaska farmers. We will consult with farmers on the best way to distribute this information to be most accessible (e.g., web, newsletters, paper).

New farmer extension and technological support: Melissa Good (Alaska Sea Grant mariculture specialist) and an expert farmer (who will be compensated for their time) will be available to answer questions and assist new farmers with the challenges of starting a new farm.

Training workshops: Melissa Good will offer at least two training workshops per year on a variety of topics and in a variety of modalities. Topics of these workshops will be responsive to needs of the industry. For example, workshops could be offered on the following topics: Farm Startup Training, Water Quality Monitoring, Production Techniques, Seafood Product Development Demonstration, Direct Marketing Training, and other topics identified by farmers. These kinds of training workshops have been very popular in the last several years. For example, Seaweed Farm Startup Training included 275 students in 2020-2021 (jointly hosted by AFDF, Alaska Sea Grant, GreenWave, Blue Evolution, ALFA, OceansAlaska).

Annual Mariculture ReCon meetings: The annual Mariculture ReCon meeting will provide an opportunity for a two-way dialogue between researchers and farmers to share interesting research results and observations on the farm. We will set aside time during the annual Mariculture ReCon meetings for farmers to share ideas and accomplishments with each other to improve farm production, build resilience to biological threats (e.g., PSP, vibrio, wet storage), as well as ideas to improve farm design and implement mechanization.

Objective 6.3: Increase social license of mariculture in the spill area.

We plan to increase public support or social license for mariculture in the spill area through a variety of outreach activities, including creating short informational videos to be shared on social media, websites, and shown on CORaL Network kiosks; participating in a variety of CORaL Network activities that engage community members throughout the spill area; and hosting community listening sessions. We will host community listening sessions in a variety of formats, such as via teleconference, Zoom or other web-based video-conference systems, and in person. The in-person listening sessions will be organized events where community leaders, Alaska Native Tribal members, elders, and the general public are invited. We will also spend time in communities in the spill area where mariculture is occurring or planned to formally meet with community leaders and informally meet with community members to hear their concerns. These concerns will be shared with the Mariculture ReCon group, who will incorporate this feedback into research considerations. Additionally, in response to listening sessions and other feedback, the outreach component will create Frequently Asked Questions (FAQs) documents which address common concerns, questions, or misinformation, utilizing past or current research whenever possible. Thus, research activities of the Mariculture ReCon group will be responsive to community concerns.

Objective 6.4: Host regulatory and management workshops.

We will host regulatory and management workshops in FY23 and FY24, including travel support, to bring together scientists, regulators, and managers from states with vibrant and growing shellfish and seaweed industries with scientists, regulators, and managers in Alaska. The topic of the first workshop will be genetic concerns related to seaweed mariculture. The topic of the second workshop will be determined with input from the mariculture industry on issues of concern.

c) Data Analysis (If Applicable), Statistical Methods (If Applicable) and Measuring Project Success

Objective 6.1: Outreach to shellfish mariculture stakeholders to communicate the findings of Farm and Business Development Components (3-5) to ensure that the findings of this study are understood by all relevant stakeholders and applied as guidance to industry development.

Objective 6.2: Technology Transfer: Mechanisms and support to share knowledge and experience in the mariculture industry.

Objective 6.3: Increase social license of mariculture in the spill area.

Objective 6.4: Host regulatory and management workshops.

Data analysis and statistical methods are not applicable. The success of Technology Transfer (6.2) will be evaluated annually through online surveys of the mariculture industry. The success of the social license efforts (6.3) will ultimately be measured by following up with concerned communities during successive community listening sessions. The success of the regulatory workshops (6.4) will be evaluated with post-workshop surveys of all participants, as well as any changes adopted by managers which improve efficiency of industry while adequately maintaining the precautionary principles to which managers must adhere.

COMPONENT 7: Administration

a) Objectives

Objective 7.1: Serve as the fiscal administrator of all non-Trustee agency awards within this mariculture team.

Objective 7.2: Serve as chief logistician of the mariculture team by facilitating all in-person and virtual (telephonic, web-based video teleconferencing) convenings of PIs.

Objective 7.3: Provide coordination of program reporting across all Trustee agency and non-Trustee agency PIs within this mariculture team.

Objective 7.4: Participate on the leadership team to provide guidance to the mariculture team and communication with the EVOSTC.

Rationale: Administrative leadership of this mariculture team will be taken on by the PWSSC. This is not a hypothesis-driven component of Mariculture ReCon. However, it is critically important to ensure sound fiscal management of all non-Trustee agency awards as well as coordination of all reporting requirements and PI meetings. Thus, the following objectives are oriented towards program management.

The awards and subawards PWSSC will manage will be to the following PIs/institutions: Bochenek—data management (Axiom); Cypher—pelagic fish (PWSSC); Decker—farm sampling (AFDF); Eckert—tech transfer, trainings, markets, education & outreach (UAF); Hoffman (PWSSC); Kelley--pelagic (UAF); Kelley—oyster brood (UAF); Konar (UAF); Umanzor (UAF). Other Principal Investigator funds in the Mariculture ReCon budget will be served directly by the PIs' employing Trustee agency.

b) Study Design, Procedural and Scientific Methods

Objective 7.1: Serve as the fiscal administrator of all non-Trustee agency awards within this mariculture team.

PWSSC will award contracts to all non-Trustee agency partners in this project. We will pursue and allow timely billing on a cost reimbursable basis. Contracts will be amended annually per approved budgets. EVOSTC funds will pass through a sponsoring agency, such as NOAA, to PWSSC. PWSSC will ensure timely submission of financial and narrative reports to the sponsoring agency through which EVOSTC funds are channeled. PWSSC will undergo an annual federal single audit and obtain annual audited financial statements to demonstrate proper fiscal management and subrecipient monitoring. We will monitor project spending by non-Trustee agency awardees and communicate proactively as necessary.

Objective 7.2: Serve as chief logistician of the mariculture team by facilitating all in-person and virtual (telephonic, web-based video teleconferencing) convenings of PIs.

PWSSC will secure in advance all logistics necessary to convene in-person annual meetings of all Mariculture ReCon Principal Investigators. This includes securing a meeting location, arranging for meals, planning for lodging, and setting up webinar, remote meeting, and teleconferencing capabilities. The Program Coordinator will work with the leadership team to solicit input and set meeting agendas, communicate meeting priorities to PIs, and help ensure Mariculture RecCon goals are being met by taking an integrative view of the project.

Objective 7.3: Provide coordination of program reporting across all Trustee agency and non-Trustee agency PIs within this mariculture team.

Provide coordination of program reporting across all Trustee agency and non-Trustee agency PIs within this mariculture team. We will ensure reporting occurs on schedule across all PIs in the program. This includes annual reports to the EVOSTC as well as any semi-annual fiscal and narrative reporting that will be required by the sponsoring agency.

Objective 7.4: Participate on the leadership team to provide guidance to the mariculture team and communication with the EVOSTC.

PWSSC Administrative Lead Hoffman, along with Science Lead Eckert, Industry Lead Decker, and Community Lead Whissel, will work closely to ensure holistic management of the collaborative team (Table 1) and achievement of the diverse objectives (Figure 1) of the group. Together, we will facilitate a sense of team among distinct investigators and create cohesion as we collectively work with stakeholders to restore, enhance, and assess the status of restoration and enhancement of natural resources and services that were injured because of the *Exxon Valdez* oil spill through mariculture activities. We will be responsive to the EVOSTC and Public Advisory Committee, and one or more members of this mariculture leadership team will attend EVOSTC and PAC meetings, when scheduled, to report out on the accomplishments of the project, answer questions, and receive feedback.

c) Measuring Project Success

Data analysis and statistical methods are not applicable to this fiscal management and program coordination work. However, success will be measured via:

- timely issuance of annual contracts to each subawardee within 30 days of sponsoring agency approval
- timely reimbursement of subawardees within 30 days of invoicing
- successful, clean completion of annual audit of financial statements and federal single audit
- smooth annual convening of Principal Investigators with logistics arranged in advance
- meeting the deadline for submittal of fiscal and narrative reports to the sponsoring fiscal agency
- attendance of EVOSTC and PAC meetings by one or more leadership team members
- timely submittal of required reports and final reports to the EVOSTC

COMPONENT 8: Data Management

Following the 1989 *Exxon Valdez* oil spill ('Spill'), several decades of scientific research has occurred to monitor the impacts and recovery to the Gulf of Alaska region and its resources. As time has lapsed, ecosystem impacts directly related to the Spill have become more challenging to detect due to regime shifts, natural variability, climate change, and other anthropogenic changes. Data collected through long-term observations and focused research are fundamental to inform management decision-making for mariculture in Alaska, and to indicate what potential restoration or enhancements actions may be possible through mariculture activities. To address these challenges and facilitate the restoration of Spill-affected resources and habitat, scientific and resource management communities need access to the most current scientific information and environmental intelligence tools to help make sound decisions.

In 2012, EVOSTC awarded the Alaska Ocean Observing System (AOOS) and Axiom Data Science (Axiom), with support from the National Center for Ecological Analysis and Synthesis (NCEAS), a data management contract entitled "Collaborative Data Management and Holistic Synthesis of Impacts and Recovery Status Associated with the *Exxon Valdez* Oil Spill." In that project, an interactive web-based data management system was successfully designed, developed, and maintained to support the data management needs of the GWA and Herring Research Monitoring (HRM) Programs and the EVOSTC. Building upon the prior data management success, AOOS and its technical partner Axiom Data Science (Axiom) were again selected as the Data Management Program provider from 2017-2021 to support continued data management activities for the GWA and HRM Programs, which included maintaining and enhancing the data management framework in response to the relative maturity of the GWA and HRM Program data sets. Starting in FY20, the Data Management Program was further expanded to provide data sharing and archiving support and services to additional EVOSTC-funded science and technical projects that were not part of the GWA or HRM Programs.

For the FY22-31 invitation, EVOSTC requires all funded programs and projects to submit data and metadata for publishing, archiving, and public access. As required by the EVOSTC, Axiom Data Science will submit a Data Management program proposal external to this Mariculture proposal. Axiom will respond to the EVOSTC's continued need for a cost-effective data management program that maintains continuity and builds upon the efforts of the prior EVOSTC data management investments. Axiom (as developer and maintainer of the AOOS system) is best situated to provide data management services to this EVOSTC-funded mariculture project by leveraging the data management system that was instituted over the prior 10-year efforts. In this proposed work, this data management system initially designed for the GWA and HRM Programs will be expanded to enhance the accessibility of data and products generated by the EVOSTC-funded Mariculture Program to ensure they are readily available to general science and natural resource management communities, both now and into the future.

a) Objectives

Objective 8.1: Initiate data management services and oversight for all EVOSTC-funded Programs and Non-Program projects.

Objective 8.2: Facilitate, monitor, and evaluate regular data submissions and metadata generation in the Research Workspace.

Objective 8.3: Provide, maintain, and modify technical infrastructure for user groups to access information produced or processed by EVOSTC-funded Programs and Non-Program projects.

Objective 8.4: Publish and promote data collected by EVOSTC-funded Programs and Non-Program projects, making them available for research, management, and general audiences.

Objective 8.5: Execute management, user feedback, and internal and external communications related to EVOSTC-funded Program and Non-Program project data and data products.

Objective 8.6: Ensure long-term preservation and dissemination into publicly accessible repositories at the term completion.

Objective 8.7: Provide access to real-time environmental data streams to support mariculture information needs at farm sites.

Rationale: The goal of the FY22-FY31 Data Management component is to provide critical data management to support the EVOSTC-funded Mariculture Program in order to assist the study team in efficiently meeting their objectives and ensuring data collected or consolidated through the effort is organized, documented, and available for their use and for future use by the larger scientific community. The Data Management Project team, consisting of Axiom Data Science, proposes to provide access to the tools and services for all EVOSTC-funded Mariculture Program projects during the EVOSTC funding period. Among these tools are the Research Workspace, a web-based data management platform; the AOOS Gulf of Alaska (GOA) Data Portal, where project data will be shared publicly; and the DataONE Member Node where final data sets will be archived for long-term preservation and broad access across multiple data repositories.

This component prioritizes data preservation and accessibility to scientific and resource management communities. This will be achieved through support for data submission and organization, metadata generation, and data transfer among study teams to assist with cross-project analysis and synthesis. Axiom software engineers will also maintain and enhance, as necessary, existing web-based tools to improve the discoverability of EVOSTC-funded project data both internally within the Research Workspace and externally through publicly accessible data repositories, including the AOOS Gulf of Alaska (GOA) Data Portal and the DataONE archive. This data curation process has been designed to meet the requirements of the EVOSTC as specified in the Data Management Project sections in the EVOSTC FY22-FY31 Invitation for Proposals. This includes the transfer of EVOSTC-funded project data to the EVOSTC storage resources at the completion of this funding term. While these tools will build upon existing systems that were developed with previous funding from multiple sources (including the EVOSTC) they are sufficiently scalable to address any new developments of the Mariculture Program, meanwhile meeting the environmental intelligence needs of researchers and resource managers required for an effective understanding of restoration and mariculture development in Spill-affected areas.

b) Study Design, Procedural and Scientific Methods

Objective 8.1: Initiate data management services and oversight for all EVOSTC-funded Programs and Non-Program projects.

A standardized data management approach is necessary to provide fundamental data management support for the Mariculture Program in sharing data sets and authoring metadata records, and for a data management system to handle many diverse data types and facilitate integration and long-term preservation. Such an approach requires the data management staff and PIs have a mutual understanding of when and what data are expected to be collected, how data can be best organized and formatted for sharing, and the expectations and goals for metadata.

Milestone 1. Convene data management meeting with Mariculture Program Managers - At the start of the program, Axiom will convene data management meetings with the Program Managers to discuss the program-level data management strategy; to make explicit the expectations for data management staff and PIs, and to verify the list of funded research projects, data collection periods, documentation of data quality control procedures, submission timelines, program outputs, and the production of any derived data products.

Milestone 2. Convene data scoping meetings with individual PIs to develop project data management plans (DMPs) - Axiom will meet with all project PIs (in person, online or by phone) to share expectations regarding what data types will be collected and delivered, timelines for data submission and metadata generation, and expected and appropriate data and file formats and naming conventions. Following these meetings, data management plans (DMPs) for each of the EVOSTC-funded projects will be established, which detail how data will be handled throughout that project's lifecycle, from collection to preservation. Agreeing to a plan at the start of the project will ensure that, from the beginning, the data are organized, well-documented and appropriately formatted for discovery, preservation, and ultimate data use for restoration and management purposes.

Milestone 3. Maintain up-to-date inventory of expected and submitted data - Using information generated during the DMP scoping, an inventory of data expected to be generated by all funded projects will be created. This inventory will describe the data sets, indicate the PI responsible for the data, and note the status of metadata for each dataset. It will be used throughout the life of the project to track the status of data sets and their metadata.

Milestone 4. Institutionalize metadata authoring- Descriptively-robust and standards-compliant metadata records are critical for long-term data access and reuse. To ensure accurate and consistent metadata authoring, Axiom will leverage procedures used for the prior GWA and HRM Programs to encourage frequent, incremental updates by project PIs to their metadata as part of their normal workflows. Specifically, Axiom develop program-specific metadata templates (as used in the GWA and HRM efforts) to assist PIs in more readily generating documentation, meanwhile ensuring sufficiently robust, standards-compliant metadata are created to ensure data are findable for re-use purposes. Throughout the project, PIs will receive training and regular communications (via email, in person, and at annual meetings) about the metadata procedures and authoring workflow.

Objective 8.2: Facilitate, monitor, and evaluate regular data submissions and metadata generation in the Research Workspace.

Project PIs and Program administrators will use the Research Workspace as a web-based platform to upload, share and discover data sets and supporting documents, and to rapidly author metadata. The system is enabled with security authentication in order to limit access to PIs, project managers, and Program administrators. Throughout the life of the project, Axiom staff will maintain oversight of timely and organized data, metadata documentation, and other program documents to the Research Workspace using a combination of data management personnel and technical infrastructure.

Milestone 1. Support and provide training for data transfer and metadata production using the Research Workspace - Experience with the use of the Research Workspace by 25 other research programs over the past six years has resulted in a system that is intuitive, easy to use, and designed to meet researcher needs. To enhance use of this system by project PIs, Axiom will host in-person and web-based training sessions in Year 1. These trainings will be scheduled as soon as is possible after the funding award. Throughout the life of the program, Axiom will continue to provide training and one-on-one assistance, as needed, to support PIs and Program Managers.

Milestone 2. Track regular data and metadata submissions - The data inventory (Obj. 1, M. 3) will be used to track data and metadata submissions to the Research Workspace against data that were expected to be generated by individual projects. On a semi-annual basis, the data management team will update the data submission records to this inventory to reflect changes in dataset and metadata status. Further, Axiom will audit the organization of data intended for publication by ensuring the types of data submitted are appropriate for long-term preservation and consistent conventions are used for naming files. This will be achieved by working directly with the PIs to implement any recommended changes identified during the audits. Indication of any data submission delays and formatting delinquencies will be identified and communicated following the procedures for addressing data non-compliance (see Section 1.C "Reporting Protocols" above). The corrective actions to address non-compliance will be implemented by the PIs with support from the Axiom data management team.

Milestone 3. Hold annual data progress meetings with individual PIs - To facilitate timely data submission and metadata authoring, Axiom will meet annually with individual PIs to discuss progress. Based on previous experiences, one-on-one meetings are an effective way to address individual metadata authoring questions, create accountability for data submissions, and strengthen relationships between PIs and data management staff. During these meetings, data management staff will revisit and make any changes necessary to the DMPs to ensure the documents are responsive to any changes or unexpected issues that arise in data collection or processing.

Milestone 4. Provide supplemental data and metadata quality control - It is the purview of the project PIs to conduct quality assurance on data collection procedures and quality control of the data themselves. Quality control by the data managers will be focused on data file formatting and on metadata documentation to ensure authoring adheres to known best practices and accurately reflects data captured within individual data files. This process will include an automated completeness check for required metadata fields; a secondary quality control check by Axiom data management staff for accuracy and consistency of metadata resulting in a list of any issues in the metadata that will be delivered to the PI; and a final check for ISO-format validation after metadata quality issues have been addressed and before submitting the dataset to national archives.

Objective 8.3: Provide, maintain, and modify technical infrastructure for user groups to access information produced or processed by EVOSTC-funded Programs and Non-Program projects.

The ultimate goal of the Data Management Project is to provide technological and staff services to assist in the organization, documentation, and structuring of data collected by EVOSTC-funded Programs and projects so that they can be transferred efficiently to long-term data archive and storage centers for future use by researchers and other user groups. This project leverages cyberinfrastructure, long-term funding, and other active data management projects previously and currently undertaken by Axiom. Project data sets will be shared with each other, documented, and shared with the public by extending and enhancing an existing technological infrastructure (see “Existing Infrastructure” section in the GWS LTRM Program- Data Management Proposal). These systems have capabilities to share, ingest, document, and archive project data and related documentation to ensure its long-term security and use.

Milestone 1. Create Research Workspace groups - At the onset of this program, a dedicated Research Workspace group for the Mariculture Program and associated projects will be created in order to organize project-level data captured under this funding period effort.

Milestone 2. Maintain automated submission pathways to national archives - The Research Workspace is connected to the DataONE Network for long-term preservation of data in the most contextually relevant environment. The intent of this capability is to ease the ingestion of data collections to national archives by simplifying the submission and upload of content and metadata. The archive pathway includes automated QA steps for preservation-ready data and metadata formats, publication agreement approval by PIs, access control to data products, services for replication and preservation of data, and DOI generation and data set citation. Throughout the life of this project, the submission pathway to DataONE will be maintained as a solution for providing long-term preservation of EVOSTC-funded program and project data.

Milestone 3. Provide scheduled and unscheduled maintenance to the system infrastructure – The data management team will perform scheduled and as-necessary maintenance to the data management system infrastructure, including the Research Workspace and GOA Data Portal, to ensure continuous operation and reliability. This may involve tasks such as applying security updates, monitoring for hardware failures, and upgrades to improve performance and capacity.

Objective 8.4: Publish and promote data collected by EVOSTC-funded Programs and Non-Program projects, making them available for research, management, and general audiences.

To maximize data use for analysis, synthesis, review, and application, and to support the restoration and management of Spill injured resources, data from EVOSTC-funded programs and projects will be made widely available through multiple pathways. During the research phase of this funding cycle, data will be securely available for internal use through the Research Workspace. When data are ready to be published, they will be made available through the existing, public-facing AOOS GOA Data Portal (https://gulf-of-alaska.portal.aoos.org/) for exploration and discovery. At the end of the fifth year (2026) and at the end of the project term, final data will be archived through DataONE for long-term preservation, noting that some process studies are longer and may require an archive timeline different than five years. National repositories have the advantage of reaching wider audiences, thus expanding the access, discoverability, and active management of data collections generated through EVOSTC-funded efforts.

Milestone 1. Prepare data and metadata into preservation-ready file formats - File formats play a key role in the ability for data access and reuse in the future. As opposed to proprietary or product-specific formats, open file formats are necessary for long-term preservation and storage, particularly in data repositories. Examples of preferred formats for different types of data include ASCII formats (TXT, CSV, XML), NetCDF, and PDF. Ultimately, it is the responsibility of the data providers to generate and document preservation-ready data formats. However, Axiom data analysts will help convert data from agreed-upon formats (used by the PIs) into preservation-ready file formats when necessary. For data sets that may stray from format standardization, Axiom data analysts will work with PIs to determine the best option for dataset preservation. Any custom scripts that are developed to convert between formats and visualize the data will be saved to streamline conversion of similar data types in the future. To ease file use and analysis by PIs that prefer proprietary or product-specific formats, the original files will be retained.

Milestone 2. Publish data and relevant program documents through the AOOS GOA Data Portal - After metadata that complies with content and quality requirements are completed, the Research Workspace will be used as a gateway to publish data and associated metadata to the AOOS GOA Data Portal, which is publicly available for discovery by researchers, managers, and general audiences. As data providers, PIs have ultimate control for managing which data are made publicly available. Within projects, PIs can individually elect to publish data folders to the portal using a simple, clearly marked checkbox. At the annual one-on-one meetings with PIs, Axiom will review the published data files with PIs to ensure no unintended publication occurs (e.g., if data have been published by another project collaborator before they are finalized).

Milestone 3. Submit all final data and metadata documents to a national archive – At the end of FY26, completed data and metadata will be submitted to DataONE, a nationally recognized long-term archive for scientific data. Process studies may not be ready for submission at that time and may not be included in the 5-year DataONE submission. However, by the end of the project term, all final data and metadata will be submitted to DataONE. Submissions will occur by initiating finalized data sets from the Research Workspace, having a final metadata review check by data management staff, and then using an automated submission process into the DataONE data federation. Research Workspace project metadata will be updated to include any identifiers associated with the data once they have been ingested into DataONE (e.g., DOI, archival accession numbers). This pathway will simplify preservation and publication for PIs while providing transparency to the data managers, program managers, and funders. Access to project data sets within DataONE and the associated data set DOIs will be exposed in the GOA Data Portal to facilitate the citation of data sets that are reused for research and management purposes.

Objective 8.5: Execute management, user feedback and internal and external communications related to EVOSTC-funded Program and Non-Program project data and data products.

The data management team will participate in Mariculture Program meetings, respond to user feedback, and maintain regular communication about project progress with the EVOSTC staff.

Milestone 1. Participate in regular program and project meetings - At the initial Mariculture Program kick-off meeting, the Axiom data management team will give an overview of the data management system and procedures to project PIs. This presentation will specifically focus on a high-level description of the tools to be used and the data management procedures employed by other EVOSTC-funded programs and projects. These procedures will also be provided in writing for reference by project PIs. Thereafter, the Axiom data management team will attend scheduled PI meetings and EVOSTC meetings (on request) to present on data management progress and receive feedback on any recommended modifications. Presentations may include topics such as the percentage of data submissions and metadata generation completed on time, new features or process updates in the data management system, and progress towards publishing data and data products. Axiom staff will also be available at PI meetings to give one-on-one training, hands-on assistance, or to answer questions about data management practices. The data management team will maintain regular contact with PIs throughout the year to ensure they have the technical support needed for the Research Workspace and their data management activities. These communications will entail notification of approaching deadlines for data or metadata submission, questions related to these submissions, and/or response to PIs about data management procedures and responsibilities questions.

Milestone 2. Continually evaluate progress and new technologies to keep pace with data management needs - Implementing a system to serve the EVOSTC-funded program and project data management needs is a core component of this proposed work. To ensure progress of the data management team in meeting these needs, regular and structured feedback is required from data management system users, i.e., the Program Managers and PIs. User feedback through surveys, group discussions, and one-on-one meetings will be gathered. The feedback will be synthesized to identify what data management methods are working well and what procedural modifications or including new technologies could be made to improve the performance of the data management system. Improvements will be prioritized based on feasibility within project funding levels and implemented as is possible.

Milestone 3. Report progress annually to the EVOSTC – The Axiom data management team will submit annual reports as detailed by the EVOSTC. These reports will document progress on objectives and milestones, as well as overall progress on project data submission and metadata generation. Reporting will also include a final report at the conclusion of the ten-year funding term.

Objective 8.6: Ensure long-term preservation and dissemination into publicly accessible repositories at the term completion.

In the final year of this 10-year effort, Axiom will ensure the completeness of all data and metadata records in the project collections. Upon request, Axiom will work with EVOSTC to develop and implement a plan to transfer all data and metadata from the data management system to EVOSTC.

Milestone 1. Ensure the existence and completeness of all data in the data inventory - In the final year of this 10-year effort, the Axiom data management team will revisit the DMP data inventory to ensure it is complete and representative of the entire legacy of data collected across projects. Using this inventory, Axiom will ensure that data and metadata generated across all years of the Mariculture Program and project activities are present, accurate, and complete. At the conclusion of this funded term, this process will provide verification of the submission of all data as a guarantee of completeness for each dataset. Any discrepancies in data and metadata completeness will be resolved between the data management team and individual PIs.

Milestone 2. Identify appropriate method of transfer for metadata and data from Axiom infrastructure to other storage resources - Upon request, in the final year of this 10-year effort, Axiom and the EVOSTC will convene to discuss the total volume of data, metadata, and derived data products; the resources necessary to securely and usefully store the data and metadata; and a path forward for system transfer. Because the proposed data management system uses Axiom's significant, leveraged, and cloud-based cyberinfrastructure, it will not be feasible to transfer the entire functionality of the data management system to local EVOSTC storage and compute resources. Similarly, with the publication of all finalized Mariculture Program data to DataONE (a fully replicated archive) and the AOOS GOA Data Portal, duplicating the data to EVOSTC servers may not be necessary. The outcome from the meeting will determine if a complete, local replicate is necessary, and if so, where data should be relocated, and the timelines and procedures for transfer.

Objective 8.7: Provide access to real-time environmental data streams to support mariculture information needs at farm sites.

Most mariculture farm sites in Alaska are in remote areas with limited bandwidth connectivity, which presents challenges for accessing real-time environmental data in a web browser using the AOOS GOA Data Portal. Axiom will provide expertise in data processing, programming, database, and application design to develop a lightweight, mobile-friendly application framework that can be used to access relevant data at mariculture farm sites.

Milestone 1. Work with Mariculture Program Manager to isolate candidate environmental data sets needed by mariculture stakeholders- The Axiom data management team will work with the Mariculture Program Manager to identify which real-time data streams are most important to stakeholders for inclusion in a lightweight data application. Additionally, the requirements and use cases for the tool will be discussed with stakeholder to help inform the design concepts.

Milestone 2. Develop and test backend web services and front-end application framework to support a mobile data integration application- Using requirements gathered from the stakeholder group, Axiom will develop a mobile, data integration application to support the mariculture communities' information needs. This application will leverage the existing backend capabilities of the AOOS data system and the AOOS GOA data portal to deliver a lightweight mobile option for accessing candidate environmental datasets at remote farm sites. In the first project year, a single stakeholder group would be chosen to pilot the application and provide feedback for future improvements.

Milestone 3. Iteratively optimize mobile application based upon user feedback- The application will be revised and optimized in additional project years using feedback for users who are accessing data at mariculture farm sites

c) Technical Design

The exact data management procedures for EVOSTC-funded Mariculture Program projects using the Research Workspace are described in the Data Management Program proposal (submitted separately). The Data Management Program requires all EVOSTC-funded project PIs to adhere to the EVOSTC Data Policy and key data management policies listed below:

- All data are to be posted on the Research Workspace groups as soon after collection as is possible in order to promote internal integration and sharing within the project.
- Final QA/QC versions of data are to be added to the Research Workspace alongside the initial (raw) versions.
- Comprehensive standards-compliant metadata will be required for each final dataset.
- Metadata shall be authored by the PIs iteratively throughout the data workflow process using the Research Workspace metadata editor unless individual agencies provide or require other means of creating metadata and provide a standards-compliant metadata record to be uploaded into the Research Workspace.
- Data from monitoring studies will be made available to the public as soon as they have been QA/QC'd, or within one year following collection, whichever is sooner. Data from process studies, which are research-oriented in nature and do not have an annual component, will be made available at the end of the project.
- Anyone making public use of another team member's data should contact the collector of the data and provide appropriate attribution and credit.
- All PIs and program and project managers are expected to adhere to EVOSTC policies regarding retention of all documents, correspondence (electronic and paper), samples, and data per the terms of the EVOSTC court settlement.

d) Reporting Protocols

The Data Management Program team also will implement a data submission compliance protocol described below to ensure EVOSTC-funded project PIs are submitting data and metadata for publishing, archiving, and public access as directed by an agreed- upon data submission schedule, to be determined at the start of a project funding cycle:

- Project PIs that fail to submit timely data and metadata in accordance with the above procedures are subject to corrective action, including recommendation to withhold a portion of the funds until compliance is met. An administrative file and metadata inventory tool within the Research Workspace will be used to identify potential PI non-compliance with data submission. At the annual one-on-one PI meetings (scheduled six months prior to annual report submission), the PI will be notified by the data management team of any shortfalls to their data submission and metadata authoring. Thereafter, the PI must correct any shortfalls within three months and steps must be taken to ensure future timeliness of submissions.

- Following a failure to correct these submissions within three months, an Out of Compliance notification will be submitted by the Data Management Project team to the project PI(s). Clear documentation will be provided of what is required to correct any non-compliance. Together with the notification, internal controls will be discussed with the project PIs to determine root causes of non-compliance and to adjust expected timetables or help ensure the PI maintains compliance in the future. Internal controls may include updates to the Research Workspace organization, ongoing training of the PIs, and/or additional data management support (e.g., metadata or database templates, one-on-one meetings, etc.). Thereafter, the PI must correct any non-compliance within three months and steps must be demonstrated to ensure future compliance.

- After these corrective actions, if the PI still fails to submit data, a Non-Compliance report will be submitted by the data management team to the EVOSTC during the annual report cycle. The Non-Compliance report will detail the nature of the non-compliance and corrective action steps taken by the data management team and by the relevant PI(s). The report may also include a recommendation for financial withholdings until compliance has been achieved.

5. COORDINATION AND COLLABORATION

A. With the Alaska SeaLife Center or Prince William Sound Science Center

Prince William Sound Science Center staff are core participants in both the leadership and research aspects of Mariculture ReCon. PWSSC will provide administrative, fiscal management, and coordination services to the overall team, as well as employ scientists who conduct research to meet the goals of this team’s approach. We are aware of the education and outreach proposal being submitted by the Alaska SeaLife Center in collaboration with other partners; PWSSC and Alaska Sea Grant are two members of that CORaL Network team. We expect that the Mariculture ReCon PIs will engage with ASLC, PWSSC, and other outreach and engagement purveyors when requested through the CORaL Network, providing both efforts are funded.

B. **With the EVOSTC LTRM Program**

There is direct overlap between members of this mariculture proposal and members of the EVOSTC LTRM proposal (PIs Campbell, Cypher, Hoffman, Konar, and Schaefer), and an understanding and awareness that exchange of data and information will occur between the two proposal groups, as well as sharing of logistical knowledge. The LTRM team collects data and has knowledge of the ecosystems that will be useful to this team and vice versa. PI Hoffman also sits on the LTRM program management team.

LTRM Environmental Drivers Component

During the late-fall and late-winter surveys, we will share a PWSSC research vessel (R/V New Wave) with the Monitoring of Oceanographic Conditions in PWS project (PI Campbell; 22120114-G) and use the equipment of that project.

Gulf Watch Alaska environmental monitoring data will provide important spatial context for the data from the production arrays. Some buoys used in the EVOSTC LTRM program will be used as non-farm "control" sites, allowing us to compare water column parameters inside and far outside from mariculture operations.

LTRM Pelagic Monitoring Component

During the late-fall and late-winter surveys, we will share a PWSSC research vessel (R/V New Wave) with the Long-term Monitoring of Marine Bird Abundance and Habitat Associations during Fall and Winter in PWS project (PIs Bishop and Schaefer; 22120114-E). These data will also complement the PWS Marine Bird Summer Surveys conducted every two years by US Fish & Wildlife (PIs Kuletz and Kaler; 22120114-M) and the Seward Line surveys (PIs Hopcroft and Kuletz; 22120114-L).

Data collected in this proposal will closely complement the long-term data collected by the Prince William Sound Science Center, specifically data on plankton communities and water column parameters.

LTRM Nearshore Monitoring Component

GWA Nearshore co-PI Konar is also co-PI of Component 2B, benthic communities, of the EVOSTC Mariculture ReCon proposal. She is interacting with other mariculture proposal components to ensure that everyone is aware of the data streams and activities of both projects. She is, therefore, well positioned to ensure future communication between the two projects. Because most mariculture efforts occur in nearshore waters, the conceptual link and information exchange between the two projects is natural. Nearshore monitoring in the vicinity of eDNA sampling sites across the three regions will be used to contextualize eDNA findings.

These data will complement the marine bird and mammal data collected as part of the nearshore surveys in Kenai, Katmai, and PWS (PI Coletti; 22120114-H) which use the same methods for recording and processing data, facilitating region-wide comparisons of marine bird and mammal survey data.

LTRM Lingering Oil Monitoring Component

We will communicate with the Lingering Oil Monitoring Component to determine if they would like any samples that we could collect for them. We are not aware of any lingering oil concerns at any of our proposed study sites.

LTRM Herring Research and Monitoring component

The monitoring efforts of the Mariculture ReCon project will complement several HRM projects that will be operating in the same bays and at similar times during the FY22-31 program. Fish biomass data will complement an HRM larval process study (PI Cypher; 22220111-H) by providing ichthyoplankton abundance from zooplankton sampling and fish biomass within Simpson Bay, a shared sample location. This will inform both projects by determining the abundance of fish larvae associated with farms and the potential impact of higher fish density on larval herring. This proposed work will also use data from aerial forage fish surveys (PI Pegau; 22220111-K) conducted annually in June to assess the number and size of forage fish schools in Simpson, Sheep, and St. Matthews Bays. Our fish, marine bird, and mammal observations will also inform data synthesis projects within the HRM program by quantifying abundance of potential predators in relation to herring rearing bays and spawning areas. We will share our results of benthic fish sampling with the Herring Research and Monitoring Component to ascertain if any of our results may be of interest to them. Herring monitoring data will be compared to the eDNA and zooplankton analyses.

Synthesis and Modeling Component

PIs and postdocs will contribute data and analysis for synthesis and modeling activities undertaken during FY22-31 in collaboration with projects within the Mariculture Focus Area and GWA.

Data Management Program

Data and metadata submission will be completed in accordance with the overall project timeline and in collaboration with Axiom Data Science. Data and metadata will be submitted for publication on the Gulf of Alaska Data Portal and DataOne within the timeframes required. Details are provided in the data management program description included here.

C. **With Other EVOSTC-funded Projects (not within the LTRM Focus Area)**

Not applicable.

D. **With Other Proposed EVOSTC Mariculture Focus Area Projects**

If other mariculture projects or mariculture-relevant restoration projects are funded, we anticipate information exchange with those entities whose work will likely be complementary to our efforts.

E. **With Proposed EVOSTC Education and Outreach Focus Area Projects**

We have integrated our Education and Outreach activities with the Community Organized Restoration and Learning (CORaL) Network. The outreach framework as proposed by the CORaL Network program will connect scientists with educators and community members with our proposed EVOSTC-funded Mariculture projects happening across the region. Alaska Sea Grant has been identified to hold a key liaison role between the Mariculture ReCon component leads and the CORaL Network program. Alaska Sea Grant will coordinate with mariculture component leads during the building phases of these two programs to develop network pathways that will continue to be available to EVOSTC-funded Mariculture projects over the life of the programs. Mariculture component leads will be members of the network and will actively participate in online resources and discussions, use of the online data portal, community events, cultural and communication learning opportunities, the intern institute, new and existing community science resources, and/or the collaborative mini-grants projects.

It is our understanding that the goal of the collaborative CORaL Network is to leverage and enhance existing outreach pathways within the *Exxon Valdez* oil spill-impacted region to ensure that current scientific information and activities are publicly accessible and serve ongoing, community-identified needs. We are committed to working closely with CORaL partners towards the sustainability of the collaborative infrastructure proposed by the CORaL Network program. Through capacity-building activities such as building a network hub, raising communication and cultural competence skills among scientists and educators, catalyzing community conversations that weave together traditional knowledge and western science activities, creating pathways to data utilization and science skills within the regional communities, and funding emerging partnerships between scientists and community/tribal entities, we believe the CORaL Network will have lasting impacts on the restoration of the region's critical resources for advancement of the sciences and the benefit of the region's residents.

F. **With Trustee or Management Agencies**

Project funding will be routed from the EVOSTC via a Trustee agency to the PWSSC to administer non-Trustee agency awards. PWSSC is poised to develop an efficient, professional relationship with any grants and contracts officers assigned to us, both at the sponsoring agency and subaward entities. PWSSC is a partner able to streamline and simplify the Trustee Council's grantsmanship needs by serving as a central node between the sponsoring agency and many subawardees. This reduces administrative burden on the Trustee Council and the agency through which funds are delivered.

ADF&G, an EVOSTC trust agency, is leading the evaluation of marine mammal interactions and mitigation measures. The need for this work is informed by: the ADF&G Marine Mammal Program's previous experience responding to farm permit application review requests; direct requests by NOAA Fisheries to ADF&G for new marine mammal - mariculture research, marine mammal management agency questions and community feedback to our program regarding mariculture and marine mammals, knowledge of marine mammal species' conservation status, and our ongoing research projects in the regions covered by this proposal.

Project data and outcomes from all components will be made available to other agencies for data synthesis and/or collaboration to support EVOSTC Trustee agency work.

G. **With Native and Local Communities**

The Native Village of Eyak is a core participant in this program. John Whissel serves on the Mariculture ReCon leadership team, and the Native Village of Eyak's roughly 100-acre farm will be one of the study areas for the farmer-led research component. Project funds for NVE's role as Community Lead will be disbursed via the Prince William Sound Science Center, and project funds to NVE as a farmer partner will be disbursed by the Alaska Fisheries Development Foundation. As a place-based community benefit organization, PWSSC is deeply embedded in Cordova. The Native Village of Eyak is Cordova's federally recognized Alaska Native Tribe. PWSSC and NVE have a mutually beneficial relationship. While the two entities operate autonomously, lines of communication are open, and NVE tribal staff and PWSSC science and education staff are accustomed to supporting each other when possible. Historically, this has occurred via partnering on research proposals and research logistics; by trading technical staff; and by promulgating community programming. In the Mariculture ReCon project, it will occur via fiscal administration, program leadership, and research collaboration. Further, key Alaska Native entities in the spill affected region are members of the CORaL Network core team: specifically, the Alutiiq Museum and the Chugach Regional Resources Commission. Mariculture ReCon has stated our plan to collaborate with the CORaL Network, whose core team members can help direct information exchanges between Alaska Native communities and EVOSTC-funded programs as necessary and appropriate.

We have also stated our intent to communicate with Gulf Watch Alaska, a program that will be engaging tribal leaders. Working with the CORaL Network and Gulf Watch Alaska to identify nodes for engagement with Alaska Native communities will help decrease the potential for burdensome, high-volume requests for participation or information exchanges with small villages. Rather, we will coordinate between and among EVOSTC-funded programs to ensure preferred communication channels and frequencies in villages in the region are not overwhelmed. EVOS had long-lasting effects on subsistence resources upon which Alaska Native community members depend, and the Mariculture ReCon program has the potential to document outcomes and practices that may offer cultural, social, and economic benefits to Alaska Native communities in the wake of goods and services that were lost to the spill. Additionally, the integration of farmers as research partners ensures direct local involvement (and benefit) as a result of the Trustee Council's investment in mariculture, and this will happen throughout the spill affected region as our farmer partner locations are geographically distributed among PWS, Kachemak Bay, and Kodiak. Lastly, CORaL Network partners budgeted for kiosks in which to display information such as data visualizations and videos about EVOSTC-funded research. PWSSC will host one of these kiosks in Cordova; other kiosks will be in Seward, Homer, Kodiak, and possibly even Valdez in the future. These kiosks will provide an informal learning opportunity about Mariculture ReCon that local community members can pursue on their own time, in addition to more formal stakeholder engagement activities in which the project will participate.

6. DELIVERABLES

Websites

Prince William Sound Science Center will maintain an up-to-date project description on their website. Scientists will provide social media and blog posts about their work, to be shared on institutional accounts and websites, such as Alaska Sea Grant, the Alaska Fisheries Development Foundation, the Native Village of Eyak, and Prince William Sound Science Center.

Reports

Annual and final reports will be submitted in accordance with EVOSTC guidelines. Reports to the sponsoring Trustee agency through which the non-Trustee agency funds are passed will be completed on the schedule required by that agency.

Management reports will be prepared on marine mammal interactions, including photographs, locations, gear types, and success of marine mammal mitigation measures.

Presentations and Publications

Annual talks from PIs, postdocs, and graduate students will be offered at a variety of relevant venues, such as the Alaska Marine Science Symposium, the Alaska Shellfish Growers Association conference, the Kachemak Bay Science Conference, Kodiak Area Marine Science Symposium, PWSSC Tuesday Night Lecture Series, and other relevant industry, community, and society gatherings. Articles for lay audiences will be printed via outlets such as *Delta Sound Connections* and local newspapers in the spill affected area.

Videos

A series of short videos will be produced over the course of this project to communicate general information about mariculture to the public as well as share cool findings and research results. These videos will be shared on social media through organizational accounts (e.g., PWSSC, Alaska Sea Grant) as well as included in kiosks developed by the Community Organized Restoration and Learning (CORaL) Network.

Proposed Manuscripts

1. *Environmental parameters associated with increased shellfish and seaweed production at mariculture farms in Alaska.*
2. *Shellfish farming and phytoplankton in Alaska: can oysters reduce phytoplankton productivity?*
3. *Comparison of performance of diploid and triploid oysters grown in Alaska*
4. *Heavy metals in farmed and wild seaweeds in Alaska*

5. *The effects of polyculture on oyster condition and biomarkers using controlled experimental sample arrays across Southcentral Alaska*.
6. *Regional and seasonal effects of polyculture on commercial oyster quality from across Southcentral Alaska.*
7. *The importance of kelp to oyster nutrition in a commercial polyculture setting: evidence from fatty acids and stable isotope approaches.*
8. *The role of oceanographic context in determining kelp and oyster growth across Southcentral Alaska*
9. *Zooplankton community response to kelp and oyster mariculture*
10. *Ecological community response to kelp and oyster aquaculture using eDNA*
11. *Impacts of mariculture on carbonate chemistry variability across three Alaska bioregions*
12. *Estimating CO_2 flux measurements for kelp mariculture: potential mechanism for quantifying CO_2 sequestration for carbon credit valuation*
13. *Estimating nearshore carbonate system dynamics using a regression modeling approach*
14. *The effects of aquaculture operations on nearshore water chemistry and hydrography.*
15. *Sporophyte density influences the morphology, carbon and nitrogen content, and yields of farmed sugar kelp, Saccharina latissima, from Southcentral Alaska.*
16. *Impacts of seeding density on morphometric traits, yields, and compositional content of farmed winged kelp, Alaria marginata, from Southcentral Alaska.*
17. *Effect of seeding density and farm setups on the photosynthetic performance of sugar kelp and winged kelp from Alaska.*
18. *Effects of pre-harvest trimming on morphometric traits, yields, and compositional content of farmed sugar kelp and winged kelp in the northern Gulf of Alaska.*
19. *Impacts of pre-harvest distal-end trimming the photosynthetic activity of farmed sugar kelp and winged kelp from the northern Gulf of Alaska.*
20. *Salinity and thermal tolerance of juvenile sporophytes sugar kelp and winged kelp from the Alaska NW Pacific*
21. *Benthic community response to environmental variables associated with kelp mariculture farms*
22. *Oyster farms and their environmental correlates influence benthic community structure*
23. *Mariculture farms as a nursery for juvenile fishes*
24. *The influence of oyster and seaweed farms on fish, invertebrate, macroinfauna, and seaweed assemblages*
25. *Carrying capacity of mariculture in PWS with and without a simulated heat wave*
26. *Short term impacts of establishing mariculture farms on benthic communities*
27. *Fouling communities associated with mariculture farm structures*
28. *Influence of mariculture farms on the size and growth of epibenthic organisms*
29. *Mariculture effects on oceanographic conditions and ecosystem dynamics in the EVOS-affected area*
30. *Mariculture effects on recovery and status of EVOS-affected species*

31. *Influence of family and region on the growth and physiological performance of farmed Crassostrea gigas in Alaska*
32. *Gene expression bioindicators of growth and performance after five generations of selective breeding of Magellena gigas in Alaska*
33. *Marine mammal interactions and mitigation measures at shellfish and seaweed farms in Alaska*

Datasets (with metadata)

1. Carbonate chemistry measurements: hourly measures of pH, temperature, salinity, oxygen concentration and PAR, inside and outside of mariculture operation at 3 farms in three separate bioregions
2. Physical measurements inside and outside of mariculture operations in Kachemak Bay, Kodiak Island, and Prince William Sound (three sites per region): temperature, salinity, dissolved oxygen, chlorophyll-a fluorescence, turbidity, PAR, nutrients.
3. Morphometric and compositional measurements of kelp and oysters grown in production arrays
4. Morphometric and compositional measurements of kelp and oysters grown in commercial polyculture and monoculture
5. Zooplankton composition, abundance, and biomass
6. eDNA data
7. Morphometrics, carbon and nitrogen content, estimated yields, and photosynthetic parameters of sugar kelp and winged kelp as a function of density
8. Morphometrics, carbon and nitrogen content, estimated yields, and photosynthetic parameters of sugar kelp and winged kelp as a function of trimming.
9. Benthic fish, epibenthic invertebrate, macroinfauna, and seaweed composition, abundance, and biomass at oyster and seaweed farms
10. Size and growth rates of targeted epibenthic invertebrates and seaweeds
11. Fouling community structure associated with mariculture farm structures
12. Static physical attributes associated with mariculture farms (substrate, depth, exposure, distance to freshwater)
13. Pelagic fish abundance, species diversity, and behavior associated with mariculture farms.
14. Trophic flow estimates between species (a proxy for ecosystem dynamics) in PWS bays.
15. Farm carrying capacity estimates for PWS bays.
16. Multiple distinct oyster lineages, one lineage specifically optimized for Alaska's unique marine conditions (pedigrees)
17. Growth rate models of individual oyster lineages
18. Survival and growth rates across sites and generations of individual oyster lineages
19. Gene expression profiles-bioindicators of growth performance (*SCPb*, ATP synthase, peptidylprolyl isomerase) of individual oyster lineages
20. Shell composition of individual oyster lineages

21. Marine mammal interactions with farm gear, including species, location, gear type, photographs
22. Marine mammal mitigation measures and success rates
23. Seabird community response to mariculture sites in PWS

Deliverables for fiscal administration, logistics, and program coordination

1. Annual contracts awarded to subawardees and contracted parties
2. Circulation of annual PI meeting notes to all team members
3. Attendance at any EVOSTC and/or PAC meetings
4. Submittal of an annual report on fiscal administration, logistics, and program coordination to EVOSTC
5. Submittal of required grant reports to fiscal sponsor
6. Completion of federal single audit and audit of financial statements
7. Coordination and submittal of a final report

Deliverables from Data Management include:

- A dedicated Research Workspace group for the EVOSTC-funded Mariculture Program and associated projects
- Regular Research Workspace and metadata training to PIs
- EVOSTC-funded Mariculture Program data management plan
- Annual reports to the EVOSTC, including a data submission inventory
- Annual updates to project data and metadata in the Research Workspace and published to the AOOS GOA Data Portal
- Final curated data sets archived in DataONE and issued a citable DOI
- Final transfer and storage of data, as necessary, to EVOSTC
- Mobile data integration application for real-time environmental data access at mariculture farm sites

7. PROJECT STATUS OF SCHEDULED ACCOMPLISHMENTS

Project milestones and planned task progress schedules are described within each of the tables below.

Project Timeline, Milestones, and Tasks

Table 2. These timelines, milestones, and tasks will be accomplished by PIs **Umanzor, Hollarsmith, Kelley, Pinchuk, Eckert, and Campbell**. Objectives addressed by these activities include Component 1: Mariculture and the physical environment, objectives 1.1, 1.2, and 1.4; Component 2: Mariculture interactions with biological communities, objectives 2A.1 and 2A.2, and Component 3, Enhancing farm production, objective 3A - Regional Variation.

Milestone/Task	FY22				FY23				FY24				FY25				FY26			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone Objective 1																				
Equipment purchase/calibration		X	X	X																
Carbonate system deployment					X															
Sensor data/bottle sampling							X		X		X		X			X				
Carbonate chemistry data analysis								X		X		X		X		X	X		X	C
Carbonate chemistry model prep																			X	C
Milestone Objective 1b																				
Purchasing/testing equipment	X	X	X	X																
Zooplankton and eDNA sampling																				
Sample processing																				
Data analysis and synthesis																				
Milestone Objective 3A																				
Coordination/training with farmers			X	X																
Kelp and oyster sampling						X	X	X	X	X	X	X	X	X	X					
Sample processing							X	X			X	X			X	X				
Data analysis																X	X	X	X	X
Fatty acid analyses									X	X	X	X	X	X	X	X				
Isotope analyses									X	X	X	X	X	X	X	X				
Polyculture kelp/oyster sampling																				
Reporting																				

*Annual reports					X				X				X				X			
Final report																		X	X	X
Deliverables																				
Peer reviewed papers																	X	X	X	C
Data posted online												X				X				X

Milestone/Task	FY27				FY28				FY29				FY30				FY31			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone Objective 1a																				C
Equipment purchase/calibration																				
Carbonate system deployment																				
Sensor data/bottle sampling																				
Carbonate chemistry data analysis																				
Carbonate chemistry model prep																				
Milestone Objective 1b																				
Purchasing/testing equipment																				
Zooplankton and eDNA sampling	X	X	X	X	X	X	X	X	X	X	X	X								
Sample processing		X	X	X	X	X	X	X	X	X	X	X	X	X						
Data analysis and synthesis									X	X	X	X	X	X	X	X	X	X		
Milestone Objective 3A																				
Coordination/training with farmers																				
Kelp and oyster sampling	X	X	X	X	X	X	X	X	X	X										
Sample processing		X	X			X	X			X	X									
Data analysis												X	X	X	X	X	X			
Fatty acid analyses	X	X	X	X	X	X	X	X	X	X	X	X								
Isotope analyses	X	X	X	X	X	X	X	X	X	X	X	X								
Polyculture kelp/oyster sampling																				
Reporting																				
*Annual reports					X				X				X				X			
Final report																		X	X	X

Deliverables																				
Peer reviewed papers																	X	X	X	C
Data posted online				X				X				X				X				X

Table 3. These timelines, milestones, and tasks will be accomplished by PIs **Konar** and **Long** from the University of Alaska and NOAA. Objectives addressed by these activities include Component 2B, Benthic Communities, objectives 2B.1-2B.6.

Milestone/Task	**FY22**				**FY23**				**FY24**				**FY25**				**FY26**			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone: Monitoring																				
Site Selection (evaluated annually)	X				X				X				X							
Recruit Graduate Student	X																			C
Supplies Purchasing	X	X																		
Sampling – Field Work			X	X		X	X			X	X			X	X					
Sample Processing			X	X			X	X			X	X			X	X	X			
Analyses				X				X				X				X	X	X		
Reporting																				
Annual reports					X				X				X				X			
Final report																				
Deliverables																				
Manuscript publications																			X	X
Contribute to data synthesis									X								X			
Present at conferences					X				X				X				X			
Website updates					X				X				X				X			
Data Upload					X				X				X				X			

Milestone/Task	FY27				FY28				FY29				FY30				FY31			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone: Monitoring																				
Site Selection (evaluated annually)	X				X				X				X							

Recruit Graduate Student	X																			C
Supplies Purchasing	X	X																		
Sampling – Field Work		X	X			X	X			X	X			X	X					
Sample Processing			X	X			X	X			X	X			X	X	X			
Analyses				X				X				X				X	X	X		
Reporting																				
Annual reports	X				X				X				X				X			
Final report																				X
Deliverables																				
Manuscript publications																			X	X
Contribute to data synthesis									X								X			
Present at conferences					X				X				X				X			
Website updates					X				X				X				X			
Data Upload					X				X				X				X			

Table 4. *PWS-Specific Ecosystem Surveys.* These timelines, milestones, and tasks will be accomplished by PIs **Cypher**, **Campbell**, and **Schaefer** from the PWSSC. Objectives addressed by these activities include 1.3, 2A.3, 2C, 2D, and 2E.1

Milestone/Task	FY22				FY23				FY24				FY25				FY26			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Expand GWA LTRM to MAR (Objs. 1.3, 2A.3, 2C.1, 2D, 2E.1)																				
Equipment purchasing		X																		
Sampling cruises		X		X	X	X		X	X	X		X	X	X		X	X	X		X
Sample processing/data analysis				X		X		X		X		X		X		X				X
Fish imaging sonar (2C.2, 2C.3)																				
Equipment purchasing		X																		
Imaging sonar cruise (2C.2)					X			X	X			X	X			X	X			X
Data analysis					X			X	X			X	X			X	X			X
Compare sonar data to eDNA (2C.3)									X				X				X			
EcoPath modeling (2C.4)																				

Hiring of postdoctoral researcher				X	X															
Data compilation							X	X	X				X				X			
Data processing and model prep										X	X	X		X	X	X				
EcoPath modeling																X	X	X	X	X
Model adaptation to other regions																				
Reporting																				
Annual reports					X				X				X				X			
Final Report																				
Deliverables																				
Manuscript publication																	X			
Contribute to Data synthesis									X											
Present at conferences									X								X			
Delta Sound Connections									X				X				X			
Website updates					X				X				X				X			
Data Upload					X				X				X				X			

Milestone/Task	FY27				FY28				FY29				FY30				FY31			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Expand GWA LTRM to MAR (Objs. 1.3, 2A.3, 2C.1, 2D, 2E.1)																				
Equipment purchasing																				
Sampling cruises	X	X		X	X	X		X	X	X		X	X	X		X				
Sample processing/data analysis	X			X	X			X	X			X								
Fish imaging sonar (2C.2, 2C.3)																				
Equipment purchasing																				
Imaging sonar cruise (2C.2)	X			X	X			X	X			X								
Data analysis	X			X	X			X	X			X	X	X						
Compare sonar data to eDNA (2C.3)	X				X				X				X	X						
EcoPath modeling (2C.4)																				
Hiring of postdoctoral researcher																				
Data compilation																				

Data processing and model prep																				
EcoPath modeling	X	X	X	X	X	X	X	X												
Model adaptation to other regions									X	X	X	X	X	X						
Reporting																				
Annual reports	X				X				X				X							
Final Report																	X			
Deliverables																				
Manuscript publication													X				X			
Contribute to Data synthesis									X											
Present at conferences	X								X				X				X			
Delta Sound Connections	X				X				X				X				X			
Website updates	X				X				X				X				X			
Data Upload	X				X				X				X				X			

Table 5. These timelines, milestones, and tasks will be accomplished by PI **Umanzor** from the University of Alaska Fairbanks. Objectives addressed by these activities include Component 3: Enhancing farm production, objectives 3C1, 3C2, and 3C3.

Milestone/Task	FY22				FY23				FY24				FY25				FY26			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Objective 3C.1											C									
Measure photosynthetic activity and morphometrics					X	X														
Data processing and analysis						X	X	X												
Objective 3C.2 - sugar kelp																C				
Measure photosynthetic activity and morphometrics					X	X			X	X										
Sample processing							X	X			X	X								
Data processing and analysis												X	X	X	X					
Objective 3C.2 - sugar kelp																				C
Measure the effect of trimming on kelp performance													X	X			X	X		
Sample processing															X	X	X	X	X	

Data processing and analysis																X	X	X	X	
Objective 3C.3 – sugar kelp																				C
Salinity and temp effect on juvenile sporophytes														X	X	X	X	X		
Data processing and analysis																	X	X	X	
Reporting																				
*Annual reports									X				X				X			
Final report																				
Deliverables																				
Peer-reviewed paper																				X
Data posted online									X				X				X			

Milestone/Task	FY27				FY28				FY29				FY30				FY31			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Objective 3C.1																				
Measure photosynthetic activity and morphometrics																				
Data processing and analysis																				
Objective 3C.2 – winged kelp																	C			
Measure photosynthetic activity and morphometrics	X	X			X	X														
Sample processing			X	X			X	X												
Data processing and analysis								X	X	X	X									
Objective 3C.2 – winged kelp																				C
Measure the effect of trimming on kelp performance									X	X			X	X						
Sample processing											X	X			X	X				
Data processing and analysis																X	X	X	X	
Objective 3C.3 – sugar kelp																				
Salinity and temp effect on juvenile sporophytes																				
Data processing and analysis	X				X				X				X				X			

Reporting																				X
*Annual reports																				
Final report																	X			X
Deliverables	X					X			X				X				X			X
Peer-reviewed paper																				
Data posted online																				

Table 6. These timelines, milestones, and tasks will be accomplished by PI **Rehberg** from ADF&G. Objectives 2E.2, 2E.3, and 2E.4 are addressed in the Marine Mammal sub-component. Activity 2E.1 is on Table 4.

Milestone/Task	**FY22**				**FY23**				**FY24**				**FY25**				**FY26**			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Objective 2E.2																				
Cooperatively design farmer surveys	X	X	X																	
Obtain farmer survey data				X				X				X				X				X
Summarize survey data					X	X			X	X			X	X			X	X		
Objective 2E.3																				
Install time-lapse cameras		X	X																	
Service cameras and retrieve data						X				X				X				X		
Analyze camera data							X	X			X	X			X	X			X	X
Objective 2E.4																				
Focused mitigation discussion and planning																X	X	X	X	X
Reporting																				
Annual reports					X				X				X				X			
Final Report																				

Deliverables																				
Interim results to study participants					X				X				X				X			
Marine mammal interaction workshop																X				X
Present at conferences									X											
Lay audience article or presentation													X							

Milestone/Task	FY27				FY28				FY29				FY30				FY31			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Objective 2E.2																				
Obtain farmer survey data				X				X				X				X				
Summarize survey data					X	X			X	X			X	X			X	X		
Objective 2E.3																				
Service cameras and retrieve data		X																		
Analyze camera data			X	X	X	X	X	X												
Objective 2E.4																				
Focused mitigation discussion & planning	X																			
Cooperative mitigation trials		X	X	X	X	X	X	X	X	X	X	X	X	X						
Summarize mitigation trials															X	X	X	X		
Reporting																				
Annual reports	X				X				X				X							
Final Report																				X
Deliverables																				
Interim results to study participants	X				X				X				X							
Marine mammal interaction manuscripts					X	X	X	X									X	X	X	X
Present at conferences	X												X							
Lay audience article or presentation									X											

Table 7. These timelines, milestones, and tasks will be accomplished by PIs **Eckert**, **Decker**, **Good**, **Whissel**, **Hollarsmith**, and **Kelley**. They address objectives 3A.3, 3B.1, 3B.2, and 3B.3 from Component 3: Enhancing farm production.

	FY22				FY23				FY24				FY25				FY26			
Milestone/Task	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone: breeding program																				
Set up wet lab space	X	X	X	C																
Obtain broodstock					X	C														
Spawn and rear larvae								X	X			X	X			X	X			
Milestone: Grow-out on farms																				
Grow juvenile oysters in FLUPSY									X				X				X			
Grow-out on farms										X	X	X	X	X	X	X	X	X	X	X
Milestone: Physiology																				
Growth model												X				X				X
Reporting																				
Annual reports					X				X				X				X			
Final report																				
Deliverables																				
Peer reviewed paper																	X	X	X	C
Data posted online													X				X			

	FY27				FY28				FY29				FY30				FY31			
Milestone/Task	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone: breeding program																				
Spawn and rear larvae				X	X			X	X			X	X			X	X			
Milestone: Grow-out on farms																				
Grow juvenile oysters in FLUPSY	X				X				X											
Grow-out on farms	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	C

Milestone: Physiology																				
Growth model				X				X				X				X				
Whole organism metabolism									X	X	X	X	X	X	X	X	C			
Gene expression									X	X	X	X	X	X	X	X	C			
Reporting																				
Annual reports					X				X				X				X			
Final report																	X	X	X	C
Deliverables																				
Peer reviewed paper																	X	X	X	C
Data posted online	X				X				X				X				X			

Table 8. These timelines, milestones, and tasks will be accomplished by PIs **Fong** and **Good**. They address objectives 4.1-4.4 from Component 4: Economic feasibility.

Milestone/Task	**FY22**				**FY23**				**FY24**				**FY25**				**FY26**			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone																				
Literature Review				X	X															
Expert Opinion Solicitation					X	X	X													
Seed Market Research							X	X												
Conceptual Hatchery Development								X	X	X										
Data Gatherings										X	X									
Baseline Bioeconomic Model Established											X	X								
Economic Model Simulation												X	X							
Final Report and Recommendations Preparations													X	X						
Reporting																				
*Annual reports				X				X				X		X						
Final report																				

Milestone/Task	FY27				FY28				FY29				FY30				FY31			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Reporting																				
*Annual reports																				
Final report																				X
Deliverables																				
Peer reviewed paper	X																			
Data posted online	X																			
Stakeholder, Policy Maker, & Public Webinar	X																			
Outreach Publication	X																			

Table 9. These timelines, milestones, and tasks will be accomplished by PIs **Fong, Sannito,** and **Good**. They address objective 5.1 from Component 5: Product Development.

Milestone/Task	FY22				FY23				FY24				FY25				FY26			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	[illegible]
Milestone: Product Development Cycle 1																				
Phase 1: Engagement, Secondary Information Sources and Advisory Committee	X	X																		
Phase 2. Conduct Focus Groups and/or Expert to Define Product Attributes and Survey Design		X	X	X																
Phase 3. Consumer taste Panels and/or Value Chain Intermediary Product Evaluation				X	X	X	X													
Phase 4. Dissemination of Results and Outreach Activities							X	X												

Reporting																				
*Annual reports				X				X												
Final report								X												
Deliverables																				
Peer reviewed paper									X											
Data posted online									X											
Outreach Activities and Extension Publication								X	X											
Milestone: Product Development Cycle 2																				
Phase 1: Engagement, Secondary Information Sources and Advisory Committee									X	X										
Phase 2. Conduct Focus Groups and/or Expert to Define Product Attributes and Survey Design										X	X	X								
Phase 3. Consumer taste Panels and/or Value Chain Intermediary Product Evaluation												X	X	X	X					
Phase 4. Dissemination of Results and Outreach Activities															X	X				
Reporting																				
*Annual reports												X				X				
Final report																X				
Deliverables																				
Peer reviewed paper																	X			
Data posted online																	X			
Outreach Activities and Extension Publication																X	X			

Milestone: Product Development Cycle 3																				
Phase 1: Engagement, Secondary Information Sources and Advisory Committee																	X	X		
Phase 2. Conduct Focus Groups and/or Expert to Define Product Attributes and Survey Design																		X	X	X
Phase 3. Consumer taste Panels and/or Value Chain Intermediary Product Evaluation																				X
Phase 4. Dissemination of Results and Outreach Activities																				
Reporting																				
*Annual reports																				X
Final report																				
Deliverables																				
Peer reviewed paper																				
Data posted online																				
Outreach Activities and Extension Publication																				

Milestone/Task	**FY27**				**FY28**				**FY29**				**FY30**				**FY31**			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone: Product Development Cycle 3 Cont'd																				
Phase 1: Engagement, Secondary Information Sources and Advisory Committee																				
Phase 2. Conduct Focus Groups and/or Expert to Define Product Attributes and Survey Design																				

Phase 3. Consumer taste Panels and/or Value Chain Intermediary Product Evaluation	X	X	X																	
Phase 4. Dissemination of Results and Outreach Activities			X	X																
Reporting																				
*Annual reports				X																
FY work plan																				
Final report				X																
Deliverables																				
Peer reviewed paper					X															
Data posted online					X															
Outreach Activities and Extension Publication				X	X															
Milestone: Product Development Cycle 4																				
Phase 1: Engagement, Secondary Information Sources and Advisory Committee					X	X														
Phase 2. Conduct Focus Groups and/or Expert to Define Product Attributes and Survey Design						X	X	X												
Phase 3. Consumer taste Panels and/or Value Chain Intermediary Product Evaluation								X	X	X	X									
Phase 4. Dissemination of Results and Outreach Activities											X	X								
Reporting																				
*Annual reports								X				X								
Final report												X								
Deliverables																				

Peer reviewed paper													X							
Data posted online													X							
Outreach Activities and Extension Publication												X	X							
Milestone: Product Development Cycle 5																				
Phase 1: Engagement, Secondary Information Sources and Advisory Committee													X	X						
Phase 2. Conduct Focus Groups and/or Expert to Define Product Attributes and Survey Design														X	X	X				
Phase 3. Consumer taste Panels and/or Value Chain Intermediary Product Evaluation																X	X	X	X	
Phase 4. Dissemination of Results and Outreach Activities																			X	X
Reporting																				
*Annual reports																X				X
Final report																				X
Deliverables																				
Peer reviewed paper																				X
Data posted online																				X
Outreach Activities and Extension Publication																				X

Table 10. These timelines, milestones, and tasks will be accomplished by PIs **Good, Decker,** and **Eckert**. They address objectives 6.1-6.4 from Component 6: Outreach.

Milestone/Task	FY22				FY23				FY24				FY25				FY26			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone: Objective 1																				
Task 1: Farm site visits			X			X	X			X	X			X	X			X	X	
Task 2: Create and update information clearinghouse	X				X				X				X				X			
Task 3: Farmer extension and support	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Task 4: Training workshops - exact timing TBD	X			X	X			X	X			X	X			X	X			
Task 5: Annual meetings	X				X				X				X				X			
Milestone: Objective 2																				
Task 1: Create videos and outreach materials			X				X				X				X				X	
Task 2: Host listening sessions			X				X				X				X				X	
Task 3: Create FAQs or other docs				X				X				X				X				X
Milestone: Objective 3																				C
Task 1: Host workshops								X				X								
Reporting																				
*Annual reports					X				X				X				X			
Deliverables																				
Videos and outreach materials				X				X				X				X				X

Milestone/Task	FY27				FY28				FY29				FY30				FY31			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone: Objective 1																				
Task 1: Farm site visits		X	X			X	X			X	X			X	X			X	X	
Task 2: Create and update information clearinghouse	X				X				X				X				X			
Task 3: Farmer extension and support	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Task 4: Training workshops - exact timing TBD	X			X	X			X	X			X	X			X	X			
Task 5: Annual meetings	X				X				X				X				X			
Milestone: Objective 2																				
Task 1: Create videos and outreach materials			X				X				X				X				X	
Task 2: Host listening sessions			X				X				X				X				X	
Task 3: Create FAQs or other docs				X				X				X				X				X
Reporting																				
*Annual reports					X				X				X				X			
Final report																				X
Deliverables																				
Videos and outreach materials				X				X				X				X				X

Table 11. These timelines, milestones, and tasks will be accomplished by PI **Hoffman**. They address objectives 7.1-7.3 from Component 7: Administration.

Milestone/Task	FY22				FY23				FY24				FY25				FY26			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone: Program planning & coordination																				
Annual program planning	X				X				X				X				X			
Circulate annual PI mtg. notes				X				X				X				X				X
Milestone: **Fiscal administration**																				
Issue subaward contracts	X				X				X				X				X			
Annual audit field testing				X				X				X				X				X
Milestone: Reporting																				
Annual reports					X				X				X				X			
Final report to sponsoring fiscal agency (5-year allocation)																				X

Milestone/Task	FY27				FY28				FY29				FY30				FY31			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone: Program planning & coordination																				
Annual program planning	X				X				X				X				X			
Circulate annual PI mtg. notes				X				X				X				X				X
Milestone: **Fiscal administration**																				
Issue subaward contracts	X				X				X				X				X			

Annual audit field testing				X				X				X				X				X
Milestone: Reporting																				
Annual reports					X				X				X				X			
Final report to sponsoring fiscal agency (5-year allocation)																				X

Table 12. These timelines, milestones, and tasks will be accomplished by Axiom Data Science as part of their Data Management Program commitment described in our data plan but addressed more fully in a separate program proposal. They address objectives 8.1-8.7 from Component 8: Data Management.

Milestone/Task	FY22				FY23				FY24				FY25				FY26			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4

Objective 8.1. Initiate data management services and oversight for all EVOSTC-funded Programs and Non-Program projects.																				
8.1.1 Schedule & complete initial data management meeting with Program Leads	X																			
8.1.2 Schedule & complete data management meetings with individual PIs		X																		
8.1.3 Complete & disseminate DMP for Mariculture Program & projects		X																		
8.1.4 Develop & disseminate metadata templates		X																		
Objective 8.2. Facilitate, monitor, and evaluate regular data submissions and metadata generation in the Research Workspace.																				
8.2.1 Provide Workspace and metadata training to PIs			X			X				X				X				X		
8.2.2 Semi-annual update to data inventory table		X		X	X		X		X		X		X		X		X		X	
8.2.3 Hold one-on-one meetings with PIs			X			X				X				X				X		
8.2.4 Complete QC of data formats and completed metadata				X			X				X				X				X	
Objective 8.3. Provide, maintain, and modify technical infrastructure for user groups to access information produced or processed by EVOSTC-funded Programs and Non-Program projects.																				
8.3.1 Set-up new Workspace groups	X																			

8.3.2 Serve existing infrastructure to Mariculture Program & projects	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
8.3.3 Provide scheduled and unscheduled maintenance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Objective 8.4. Publish and promote data collected by EVOSTC-funded Programs and Non-Program projects, making them available for research, management, and general audiences.																				
8.4.1 Prepare data into preservation formats				X				X				X				X				X
8.4.2 Publish data and data products through the AOOS GOA Portal				X				X				X				X				X
8.4.3 Final data collections submitted to DataONE																			X	X
Objective 8.5. Execute management, user feedback and internal and external communications related to EVOSTC-funded Program and Non-Program project data and data products.																				
8.5.1 Present data management procedures & progress at annual meetings			X				X				X				X				X	
8.5.2 Provide ongoing data and metadata support to PIs, as needed	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
8.5.3 Report progress annually to the EVOSTC					X				X				X				X			
Objective 8.6. Ensure long-term preservation and dissemination into publicly accessible repositories at the term completion.																				
8.6.1 Verify data and metadata completeness for Mariculture Program & projects																				

8.6.2 Implement, as necessary, final transfer and storage of data to EVOSTC																				
Objective 8.7. Provide access to real-time environmental data streams at farm sites to support mariculture information needs.																				
8.7.1 Isolate candidate environmental data sets needed by mariculture stakeholders		X																		
8.7.2 Develop and test application to support a mobile data integration application		X	X	X																
8.7.3 Iteratively optimize mobile application based upon user feedback					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Reporting																				
Annual reports					X				X				X				X			
Final report																				
Deliverables																				
Data uploaded to Research Workspace				X				X				X				X				X
Data posted on GOA Data Portal				X				X				X				X				X
Data archived in Data ONE																			X	X

Milestone/Task	**FY27**				**FY28**				**FY29**				**FY30**				**FY31**			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4

Objective 8.2. Facilitate, monitor, and evaluate regular data submissions and metadata generation in the Research Workspace.																				
8.2.1 Provide Workspace and metadata training to PIs			X			X				X				X				X		
8.2.2 Semi-annual update to data inventory table		X		X	X		X		X		X		X		X		X		X	
8.2.3 Hold one-on-one meetings with PIs			X			X				X				X				X		
8.2.4 Complete QC of data formats and completed metadata				X			X				X				X				X	
Objective 8.3. Provide, maintain, and modify technical infrastructure for user groups to access information produced or processed by EVOSTC-funded Programs and Non-Program projects.																				
8.3.1 Set-up new Workspace groups																				
8.3.2 Serve existing infrastructure to Mariculture Program & projects	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
8.3.3 Provide scheduled and unscheduled maintenance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Objective 8.4. Publish and promote data collected by EVOSTC-funded Programs and Non-Program projects, making them available for research, management, and general audiences.																				
8.4.1 Prepare data into preservation formats				X				X				X				X				X
8.4.2 Publish data and data products through the AOOS GOA Portal				X				X				X				X				X
8.4.3 Final data collections submitted to DataONE																			X	X
Objective 8.5. Execute management, user feedback and internal and external communications related to EVOSTC-funded Program and Non-Program project data and data products.																				

8.5.1 Present data management procedures & progress at annual meetings			X				X				X				X				X	
8.5.2 Provide ongoing data and metadata support to PIs, as needed	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
8.5.3 Report progress annually to the EVOSTC					X				X				X				X			
Objective 8.6. Ensure long-term preservation and dissemination into publicly accessible repositories at the term completion.																				
8.6.1 Verify data and metadata completeness for Mariculture Program & projects																			X	X
8.6.2 Implement, as necessary, final transfer and storage of data to EVOSTC																				X
Objective 8.7. Provide access to real-time environmental data streams at farm sites to support mariculture information needs.																				
8.7.1 Isolate candidate environmental data sets needed by mariculture stakeholders																				
8.7.2 Develop and test application to support a mobile data integration application																				
8.7.3 Iteratively optimize mobile application based upon user feedback	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Reporting																				
Annual reports					X				X				X				X			
Final report																				X
Deliverables																				
Data uploaded to Research Workspace				X				X				X				X				X

Data posted on GOA Data Portal				X				X				X				X				X
Data archived in Data ONE																			X	X

8. Budget

A. Budget Forms (Attach)

The budget is represented in two sets of 5-year increments as seen below. Additional detail is available in the Excel workbook provided with this proposal.

Budget Category:	Proposed FY 22	Proposed FY 23	Proposed FY 24	Proposed FY 25	Proposed FY 26	5-YR TOTAL PROPOSED
Personnel	$696,746	$1,072,885	$1,106,563	$1,145,540	$1,188,305	$2,086,697
Travel	$86,787	$172,078	$150,180	$138,395	$112,654	$315,486
Contractual	$506,081	$625,474	$678,937	$711,199	$701,371	$2,283,520
Commodities	$368,606	$193,834	$179,074	$123,078	$150,487	$650,028
Equipment	$591,993	$165,860	$121,758	$112,718	$68,253	$335,650
Indirect Costs (rate will vary by project)	$169,780	$189,801	$183,472	$188,785	$198,458	$568,986
SUBTOTAL	$2,419,993	$2,419,932	$2,419,984	$2,419,714	$2,419,528	$12,099,151
General Administration (9% of subtotal)	$217,799	$217,794	$217,799	$217,774	$217,757	$1,088,924
PROGRAM TOTAL	**$2,637,792**	**$2,637,726**	**$2,637,783**	**$2,637,489**	**$2,637,285**	**$13,188,075**
Other Resources (In-Kind Funds)	**$60,239**	**$62,333**	**$53,622**	**$67,787**	**$111,360**	**$355,341**

Budget Category:	Proposed FY 27	Proposed FY 28	Proposed FY 29	Proposed FY 30	Proposed FY 31	5-YR TOTAL PROPOSED	ACTUAL CUMULATIVE
Personnel	$1,161,563	$1,177,260	$1,188,384	$1,305,249	$1,327,953	$6,160,409	
Travel	$116,285	$115,865	$122,621	$113,398	$113,377	$581,547	
Contractual	$677,793	$679,787	$675,428	$618,373	$648,121	$3,299,501	
Commodities	$136,714	$141,359	$92,706	$75,550	$35,000	$481,329	
Equipment	$150,315	$127,655	$133,628	$74,054	$34,568	$520,220	
Indirect Costs (report rate here)	$177,061	$177,827	$206,919	$233,224	$260,157	$1,055,187	
SUBTOTAL	$2,419,731	$2,419,753	$2,419,686	$2,419,848	$2,419,176	$12,098,193	
General Administration (9% of subtotal)	$217,776	$217,778	$217,772	$217,786	$217,726	$1,088,837	
PROGRAM TOTAL	**$2,637,506**	**$2,637,530**	**$2,637,458**	**$2,637,634**	**$2,636,901**	**$13,187,030**	
Other Resources (In-Kind Funds)	**$37,689**	**$39,050**	**$40,607**	**$111,937**	**$128,381**	**$357,663**	

B. **Sources of Additional Funding**

Non-EVOSTC Funds to be used, please include source and amount per source:

FY22	**FY23**	**FY24**	**FY25**	**FY26**	**FY22-26 Total**
$60,239	$62,333	$53,622	$67,787	$111,360	$355,341
FY27	**FY28**	**FY29**	**FY30**	**FY31**	**FY27-31 Total**
$37,689	$39,050	$40,607	$111,937	$128,381	$357,663
				FY22-31 Total	*$610,774*

Base salary and benefits for NOAA personnel will be donated as in-kind funding. NOAA will dedicate 1 month of time for Chris Long for each year of the study at $11,145 in the first year, with 2% increase in following years. A month of time for two other Kodiak-based biologists who will be dedicated FY22-FY25 and FY27-FY30. NOAA will dedicate 1 month of Jordan Hollarsmith time for FY 22-25 and FY27-29 for project coordination, site visits, data processing and management, and initial analyses and 2 months for FY26, 30 and 31 for data analyses and manuscript preparation. NOAA will dedicate 1 month of Copeman time for FY23-25, 2 months in 2026, 1 month in FY27-29 and 2 months in 2030 and 2031 (focusing on the fatty acid analyses). NOAA will dedicate 1 month of Miller time for FY26 and FY31 for data analyses and manuscript preparation (focusing on the isotope analyses). NOAA will dedicate 1 month of Suryan time for FY26 and FY31 for data analyses and manuscript preparation (focusing on the isotope and fatty acid analyses).

9. LITERATURE CITED

Aaker, D.A., V. Kumar, R. Leone, and G.S. Day. 2012. Marketing Research. John Wiley and Sons, Hoboken, New Jersey. 664pp.

Alaska Department of Fish and Game. 2021. Aquatic Farming Oyster Production Data. https://www.adfg.alaska.gov/index.cfm?adfg=fishingaquaticfarming.aquaticfarminfo_oysters

Alaska Mariculture Task Force, 2018. Alaska Mariculture Development Plan. State of Alaska, March 23, 2018. https://www.afdf.org/wp-content/uploads/Alaska-Mariculture-Development-Plan_v2018-06-29_FINAL_digital.pdf. 82 pp.

Anderson, M.J., Gorley, R. N., and Clarke, K.R. 2008. PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods. Plymouth: PRIMER-E ltd.

Appleyard S.A., Ward R.D., 2006. Genetic diversity and effective population size in mass selection lines of Pacific oyster (*Crassostrea gigas*). Aquaculture 254: 148–159.

Batten, S. D., Moffitt, S., Pegau, W. S., & Campbell, R. 2016. Plankton indices explain interannual variability in Prince William Sound herring first year growth. Fisheries Oceanography 25(4): 420-432.

Bayne, B. L., M. Ahrens, S. K. Allen, M. A. D'Auriac, T. Backeljau, P. Beninger, R. Bohn, P. Boudry, J. Davis, T. Green, X. Guo, D. Hedgecock, A. Ibarra, P. Kingsley-Smith, M. Krause, C. Langdon, S. Lapègue, C. Li, D. Manahan, R. Mann, L. Perez-Paralle, E. N. Powell, P. D. Rawson, D. Speiser, J. L. Sanchez, S. Shumway, and H. Wang. 2017. The proposed dropping of the genus *Crassostrea* for all Pacific cupped oysters and its replacement by a new genus *Magallana*: A dissenting view. Journal of Shellfish Research 36: 545-547.

Bergman, K. C., Svensson, S., & Öhman, M. C. 2001. Influence of algal farming on fish assemblages. Marine Pollution Bulletin 42(12): 1379-1389.

Blankenship, A. B., Breen, G. E., & Dutka, A. F. 1998. State of the art marketing research. Lincolnwood, Ill: NTC Business Books. 454 pp.

Boswell, K. M., Wilson, M. P., & Cowan Jr, J. H. 2008. A semiautomated approach to estimating fish size, abundance, and behavior from dual-frequency identification sonar (DIDSON) data. North American Journal of Fisheries Management 28(3): 799-807.

Boswell, K.M., A.M. Zenone, and W.S. Pegau. 2018. Non-lethal sampling: In situ estimation of juvenile herring sizes. *Exxon Valdez* Long-Term Herring Research and Monitoring Program Final Report (*Exxon Valdez* Oil Spill Trustee Council Project 15120111-D), *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

Both, A., C. J. Byron, B. Costa-Pierce, C. C. Parrish, and D. C. Brady. 2020. Detrital subsidies in the diet of *Mytilus edulis*; Macroalgal detritus likely supplements essential fatty acids. Frontiers in Marine Science 7: 1073.

Boulais, M., K.J. Chenevert, A.T. Demey, E.S. Darrow, M.R. Robison, J.P. Roberts and A. Volety. 2017. Oyster reproduction is compromised by acidification experienced seasonally in coastal regions. Scientific Reports 7: 13276. https://doi.org/10.1038/s41598-017-13480-3

Breeman, A. M. 1988. Relative importance of temperature and other factors in determining geographic boundaries of seaweeds: experimental and phenological evidence. Helgolaender Meeresuntersuchungen 42: 199-241.

Bresnahan, P.J., Martz, T.R., Takeshita, Y., Johnson, K.S., LaShomb, M., 2014. Best practices for autonomous measurement of seawater pH with the Honeywell Durafet. Methods in Oceanography 9: 44-60.

Brown, J. R., & Hartwick, E. B. 1988. Influences of temperature, salinity and available food upon suspended culture of the Pacific oyster, *Crassostrea gigas*: I. Absolute and allometric growth. Aquaculture 70(3): 231-251.

Byron, C., Link, J., Bengtson, D., Costa-Pierce, B., 2011. Calculating carrying capacity of shellfish aquaculture using mass-balance modeling: Narragansett Bay, Rhode Island. Ecological Modelling 222: 1743-1755.

Byron, C. J., Jin, D., & Dalton, T. M. 2015. An Integrated ecological–economic modeling framework for the sustainable management of oyster farming. Aquaculture 447: 15–22.

Campbell, M.D. and Hall, S.G., 2019. Hydrodynamic effects on oyster aquaculture systems: a review. Reviews in Aquaculture 11(3): 896-906.

Campbell, R. W. 2018. Hydrographic trends in Prince William Sound, Alaska, 1960–2016. Deep Sea Research Part II: Topical Studies in Oceanography 147: 43-57.

Chang, K.-H., Doi, H., Nishibe, Y., Obayashi, Y., Nakano, S. 2009. Spatial and temporal distribution of zooplankton communities of coastal marine waters receiving different human activities (fish and pearl oyster farmings). The Open Marine Biology Journal 3: 83-88.

Chen, J.Q., M.C. Haws, Q.S.W. Fong, & P.S. Leung. 2017. Economic feasibility of producing oysters using a small-scale Hawaiian fishpond model. Aquaculture Reports 5 (2017): 41-51.

Chen, Q., X. D. Pan, B. F. Huang, and J. L. Han. 2018. Distribution of metals and metalloids in dried seaweeds and health risk to population in southeastern China. Scientific Reports 8: 3578. https://doi.10.1038/s41598-018-21732-z

Clarke, K.R. and M. Ainsworth. 1993. A method of linking multivariate community structure to environmental variables. Marine Ecology Progress Series 92: 205-219.

Clarke, K.R., and Gorley, R.N. 2015. Getting Started with PRIMER v7. Plymouth: PRIMER-E ltd.

Clarke, K.R., Gorley, R.N., Somerfield, P.J., Warwick, R.M. 2014. Change in marine communities: an approach to statistical analysis and interpretation, 3rd edition. PRIMER-E: Plymouth.

Clement, D. 2013. Effects on Marine Mammals. Chapter 4 in: Ministry for Primary Industries. Literature review of ecological effects of aquaculture. Report prepared by Cawthron Institute, Nelson, New Zealand.

Closek, C. J., Santora, J. A., Starks, H. A., Schroeder, I. D., Andruszkiewicz, E. A., Sakuma, K. M., ... & Boehm, A. B. 2019. Marine vertebrate biodiversity and distribution within the central California Current using environmental DNA (eDNA) metabarcoding and ecosystem surveys. Frontiers in Marine Science 6: 732.

Cole, V. J., Harasti, D., Lines, R., & Stat, M. 2021. Estuarine fishes associated with intertidal oyster reefs characterized using environmental DNA and baited remote underwater video. Environmental DNA 00: 1–13.

Connell, S.D. and B.D. Russell. 2010. The direct effects of increasing CO2 and temperature on non-calcifying organisms: increasing the potential for phase shifts in kelp forests. Proceedings of the Royal Society 277(1686): 1409-1415.

Copeman L.A., Parrish C.C. 2004. Lipids classes, fatty acids, and sterols in seafood from Gilbert Bay, Southern Labrador. Journal of Agricultural and Food Chemistry 52: 4872-4881.

Copeman L.A., Parrish C.C., Gregory R.S., Jamieson R.E., Wells J., Whiticar M.J. 2009. Fatty acid biomarkers in coldwater eelgrass meadows: elevated terrestrial input to the food web of age-0 Atlantic cod *Gadus morhua*. Marine Ecology Progress Series 386: 237-251.

Coyle, K.O., Paul, A.J., 1990. Abundance and biomass of meroplankton during the spring bloom in an Alaskan bay. Ophelia 32(3): 199-210.

Coyle, K.O., Pinchuk, A.I. 2003. Annual cycle of zooplankton abundance, biomass and production on the northern Gulf of Alaska shelf, October 1997 through October 2000. Fisheries Oceanography 12: 327-338.

Coyle, K.O. Pinchuk, A.I., 2005. Seasonal cross-shelf distribution of major zooplankton taxa on the northern Gulf of Alaska shelf relative to water mass properties, species depth preferences and vertical migration behavior. Deep Sea Research II 52: 217-245.

Crawford, C., Catriona, K.A., and Iona, M. 2003. Effects of shellfish farming on the benthic environment. Aquaculture 224:117-140.

Davis, R. W., Bodkin, J. L., Coletti, H. A., Monson, D. H., Larson, S. E., Carswell, L. P. and Nichol, L. M. 2019. Future directions in sea otter research and management. Frontiers in Marine Science 5: 510. DOI: 10.3389/fmars.2018.00510

De Melo, C. M. R., Morvezen, R., Durland, E., & Langdon, C. 2018. Genetic by environment interactions for harvest traits of the Pacific oyster *Crassostrea gigas* (Thunberg) across different environments on the West Coast, USA. Journal of Shellfish Research 37(1): 49-61.

Dealteris J.T., Kilpatrick B.D., Rheault R.B., 2004. A comparative evaluation of the habitat value of shellfish aquaculture gear, submerged aquatic vegetation and a non-vegetated seabed. Journal of Shellfish Research 23(3), 867–874.

Dickson, A.G., Sabine, C.L., Christian, J.R., 2007. Guide to best practices for ocean CO2 measurements. North Pacific Marine Science Organization, Sidney, BC.

Dickson, A.G., Wesolowski, D.J., Palmer, D.A., Mesmer, R.E., 1990. Dissociation constant of bisulfate ion in aqueous sodium chloride solutions to 250. degree. The Journal of Physical Chemistry C 94: 7978-7985.

Earle M., R. Earle and A. Anderson. 2001. Food Product Development. Woodhead Publishing Ltd. 392 pp.

Evans, S., & Langdon, C. 2006. Effects of genotype× environment interactions on the selection of broadly adapted Pacific oysters (*Crassostrea gigas*). Aquaculture 261(2): 522-534.

Evans, W., Mathis, J.T., Ramsay, J., Hetrick, J., 2015. On the Frontline: Tracking Ocean Acidification in an Alaskan Shellfish Hatchery. PloS one 10, e0130384.

Evans, W., Mathis, J.T., Winsor, P., Statscewich, H., Whitledge, T.E., 2013. A regression modeling approach for studying carbonate system variability in the northern Gulf of Alaska. Journal of Geophysical Research: Oceans 118: 476-489.

Exxon Valdez Oil Spill Trustee Council. 2014. 2014 Update injured resources and services list. Anchorage, Alaska.

Fang, J., J. Zhang, T. Xiao, D. Huang, and S. Liu. 2016. Integrated multi-trophic aquaculture (IMTA) in Sanggou Bay, China. Journal Aquaculture Environment Interactions 8: 201-205. https://doi.org/10.3354/aei00179

Flavin, K., N. Flavin, and B. Flahive. 2013. Kelp Farming Manual. A guide to the processes, techniques, and equipment for farming kelp in New England waters. In Ocean Approved. Portland, 123p.

Fong, Q.S.W., S. Ellis, and M. Haws. 2005. Economic feasibility of small-scale black lipped pearl oyster (*Pinctada margaritifera*) pearl farming in the Central Pacific. Journal of Aquaculture Economics and Management 9(3): 347-368.

Fox DA, Wark K, Armstrong JL, and Brown LM. 2011. Gillnet configurations and their impact on Atlantic sturgeon and marine mammal bycatch in the New Jersey monkfish fishery: year 1. [Final report; 30p.] NOAA NMFS Contract No. EA133F-10-RQ-1160.

Garcia, H.E., Gordon, L.I., 1992. Oxygen solubility in seawater: Better fitting equations. Limnology and oceanography 37: 1307-1312.

Gehri R.R., Larson W.A., Gruenthal K., Sard N., Shi Y. 2020. eDNA metabarcoding outperforms traditional fisheries sampling and reveals fine-scale heterogeneity in a temperate freshwater lake. preprint. Genomics. Available from http://biorxiv.org/lookup/doi/10.1101/2020.10.20.347203 (accessed March 17, 2021).

Gentry, R. R., Lester, S. E., Kappel, C. V., White, C., Bell, T. W., Stevens, J., & Gaines, S. D. 2017. Offshore aquaculture: spatial planning principles for sustainable development. Ecology and evolution 7(2): 733-743.

Gentry, R. R., Alleway, H. K., Bishop, M. J., Gillies, C. L., Waters, T., & Jones, R. 2020. Exploring the potential for marine aquaculture to contribute to ecosystem services. Reviews in Aquaculture 12(2): 499-512.

Gonski, S.F., Cai, W.-J., Ullman, W.J., Joesoef, A., Main, C.R., Pettay, D.T., Martz, T.R., 2018. Assessment of the suitability of Durafet-based sensors for pH measurement in dynamic estuarine environments. Estuarine, Coastal and Shelf Science 200: 152-168.

Guiné, R.P.F., S.G. Florença, M.J. Barroca, and O. Anjos. 2020. The link between the consumer and the innovations in food product development. Foods 2020 (9): 1317-1339.

Gorsky, G., Flood, P.R., Youngbluth, M., Picheral, M., Grisoni, J. M. 1999. Zooplankton distribution in four western Norwegian fjords. Estuarine, Coastal and Shelf Science 50(1): 135-141.

Guo, X., Wang, Y., Xu, Z., & Yang, H. 2009. Chromosome set manipulation in shellfish. In New Technologies in Aquaculture (pp. 165-194). Woodhead Publishing.

Hamilton J., Konar, B. 2007. Implications of substrate complexity and kelp variability for south-central Alaskan nearshore fish communities. Fish B-NOAA 105: 189-196.

Harley, C. D., K. M. Anderson, K. W. Demes, J. P. Jorve, R. L. Kordas, T. A. Coyle, and M. H. Graham. 2012. Effects of Climate Change on Global Seaweed Communities. Journal of Phycology 48: 1064-1078. https://doi.org/10.1111/j.1529-8817.2012.01224.x

Hastings, K, Rehberg, Mk. O'Corry-Crowe, G., Pendleton, G., Jemison, L. and Gelatt, T. 2020. Demographic consequences and characteristics of recent population mixing and colonization in Steller sea lions, *Eumetopias jubatus*. Journal of Mammalogy 101: 107-120. 10.1093/jmammal/gyz192.

Hazen, E. L., & Horne, J. K. 2004. Comparing the modelled and measured target-strength variability of walleye pollock, *Theragra chalcogramma*. ICES Journal of Marine Science 61(3): 363-377.

Hightower, J. E., Magowan, K. J., Brown, L. M., & Fox, D. A. 2013. Reliability of fish size estimates obtained from multibeam imaging sonar. Journal of Fish and Wildlife Management 4(1): 86-96.

Hofmann, G.E., O'Donnell, M.J., Todgham, A.E., 2008. Using functional genomics to explore the effects of ocean acidification on calcifying marine organisms. Marine Ecology Progress Series 373: 219-225.

Hollarsmith J.A., Sadowski J.S., Picard M.M.M., Cheng B., Farlin J., Russell A., Grosholz E.D. 2019. Effects of seasonal upwelling and runoff on water chemistry and growth and survival of native and commercial oysters. Limnology and Oceanography, lno.11293.

Hoppert, K, R. Mai, S. Zahn, S. Hoffmann, and H. Rohm. 2012. Integrating sensory evaluation in adaptive conjoint analysis to elaborate the conflicting influence of intrinsic and extrinsic attributes on food choice. Appetite 59 (2012): 949–955.

Izquierdo-Gomez, D., Bayle-Sempere, J. T., Arreguín-Sánchez, F., & Sánchez-Jerez, P. 2016. Modeling population dynamics and small-scale fisheries yields of fish farming escapes in Mediterranean coastal areas. Ecological Modelling 331: 56-67.

Jackson G.A., Winant C.D. 1983. Effect of a kelp forest on coastal currents. Continental Shelf Research 2: 75–80.

Jacob, D., Soldati, A., Wirth, R., Huth, J., Wehrmeister, U., Hofmeister, W., 2008. Nanostructure, composition and mechanisms of bivalve shell growth. Geochimica et Cosmochimica Acta 72: 5401-5415.

Jemison L. A., Pendleton G. W., Fritz L. W., Hastings K. K., Maniscalco J. M., Trites A. W. 2013. Inter-Population Movements of Steller Sea Lions in Alaska with Implications for Population Separation. PLoS ONE 8(8): e70167.

Jones T.O., Iwama G.K. 1991. Polyculture of the Pacific oyster, *Crassostrea gigas* (Thunberg), with chinook salmon, *Oncorhynchus tshawytscha*. Aquaculture 92: 313-322.

Jones, B., Kelley, A., Mincks, S., 2021. Changes to benthic community structure may impact organic matter consumption on Pacific Arctic shelves. Conservation Physiology In press.

Kaler, R., E. Labunski, and K.J. Kuletz. 2017. Prince William Sound marine bird surveys. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 16120114-K). US Fish and Wildlife Service, Anchorage, Alaska.

Kam, L.E.Y.W., P.S. Leung, A.C. Ostrowski and A. Molnar. 2002. Size economies of a Pacific threadfin (*Polydactylus sexfilis*) hatchery in Hawaii, Journal of World Aquaculture Society, 23(4): 410-424.

Kemper, C. M., and Gibbs, S. E. 1997. 'A Study of Life History Parameters of Dolphins and Seals Entangled in Tuna Farms near Port Lincoln, and Comparisons with Information from Other South Australian Dolphin Carcasses.' Unpublished report to Environment Australia, Canberra. 47 pp. + 25 figures.

Kemper, C. M., and Gibbs, S. E. 2001. Dolphin interactions with tuna feedlots at Port Lincoln, South Australia and recommendations for minimising entanglements. Journal of Cetacean Research and Management 3: 283–292.

Kim, J., M. Stekoll, and C. Yarish. 2019. Opportunities, challenges and future directions of open-water seaweed aquaculture in the United States. Phycologia 58: 446-461.

Konar, B., Iken, K., Coletti, H., Monson, D. and Weitzman, B., 2016. Influence of static habitat attributes on local and regional rocky intertidal community structure. Estuaries and Coasts 39(6): 1735-1745.

Kotler, P. and K. Keller. 2015. Marketing Management (15th Edition). Prentice Hall. 832 pp.

Langdon C., Evans F., Jacobson D., Blouin M., 2003. Yields of cultured Pacific oysters *Crassostrea gigas* Thunberg improved after one generation of selection. Aquaculture 220: 227–244.

Leung, P.S. and S.M. Moss. 1999. Economic assessment of a prototype biosecure shrimp growout facility, In Proceedings of Controlled & Biosecure Production Systems, Editors, R.A. Bullis and G.D. Pruder, pp. 97-106.

Levitt, G. J., R. J. Anderson, C. J. T. Boothroyd, and F. A. Kemp. 2002. The effects of kelp harvesting on its regrowth and the understorey benthic community at Danger Point, South Africa, and a new method of harvesting kelp fronds, South African Journal of Marine Science 249(1): 71-85.

Link, J.A., 2010. Adding rigor to ecological network models by evaluating a set of pre-balanced diagnostics: A plea for PREBAL. Ecologcial Modelling 221: 1580-1591.

Love, R. H. 1977. Target strength of an individual fish at any aspect. The Journal of the Acoustical Society of America 62(6): 1397-1403.

Lu Y.H., Ludsin S.A., Fanslow D.L., Pothoven S.A. 2008. Comparison of three microquantity techniques for measuring total lipids in fish. Canadian Journal of Fisheries and Aquatic Sciences 65: 2233-2241.

Lueker, T.J., Dickson, A.G., Keeling, C.D., 2000. Ocean pCO2 calculated from dissolved inorganic carbon, alkalinity, and equations for K1 and K2: validation based on laboratory measurements of CO2 in gas and seawater at equilibrium. Marine chemistry 70: 105-119.

Malhotra, N. K. 2009. Marketing research: An applied orientation. 6th edition. Pearson/Prentice Hall. 897 pp.

Mallet, A.L., Carver, C.E. and Landry, T., 2006. Impact of suspended and off-bottom Eastern oyster culture on the benthic environment in eastern Canada. Aquaculture 255(1-4): 362-373.

Martz, T. R., J. G. Connery, and K. S. Johnson. 2010. Testing the Honeywell Durafet® for seawater pH applications. Limnology and Oceanography: Methods 8:172-184.

McKinstry, C. A., & Campbell, R. W. 2018. Seasonal variation of zooplankton abundance and community structure in Prince William Sound, Alaska, 2009–2016. Deep Sea Research Part II: Topical Studies in Oceanography 147: 69-78.

Merrill, J.E. and D.M. Gillingham. 1991. Bull kelp cultivation handbook. Applied Algal Research Co. Seattle, 71p.

Meyer, E., Manahan, D., 2010. Gene expression profiling of genetically determined growth variation in bivalve larvae (Crassostrea gigas). Journal of Experimental Biology 213: 749-758.

Miller, C.A., Bonsell, C., McTigue, N.D., Kelley, A.L., 2021. The seasonal phases of an Arctic lagoon reveal the discontinuities of pH variability and CO 2 flux at the air–sea interface. Biogeosciences 18: 1203-1221.

Miller, C. A., & Kelley, A. L., 2021a. Seasonality and biological forcing modify the diel frequency of nearshore pH extremes in a subarctic Alaskan estuary. Limnology and Oceanography 66(4): 1475-1491.

Miller, C.A., Kelley, A.L., 2021b. Alkalinity cycling and carbonate chemistry decoupling in seagrass mystify processes of acidification mitigation. Scientific Reports 11: 13500. https://doi.org/10.1038/s41598-021-92771-2

Miller, C.A., Pocock, K., Evans, W., Kelley, A.L., 2018. An evaluation of the performance of Sea-Bird Scientific's SeaFET™ autonomous pH sensor: considerations for the broader oceanographic community. Ocean Science 14: 751-768.

Milliken, HO, Hopkins, N., Matzen, E. and Keane, E. 2020 Comparative studies of the catch loss of longfin inshore squid when using the TI Cable Grid in the bottom trawl fishery. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 20-02; 24 p.

Morris E.K., Caruso T., Buscot F., Fischer M., Hancock C., Maier T.S., Meiners T., Müller C., Obermaier E., Prati D., Socher S.A., Sonnemann I., Wäschke N., Wubet T., Wurst S., Rillig M.C. 2014. Choosing and using diversity indices: Insights for ecological applications from the German Biodiversity Exploratories. Ecology and Evolution 4: 3514–3524.

Moss, S. M. and P.S. Leung. 2006. Comparative cost of shrimp production: Earthen ponds versus recirculating aquaculture systems. In P. S. Leung & C. Engle (Eds.), Shrimp Culture: Economics, Market, & Trade (pp. 291-300). Ames, Iowa, Blackwell Publishing.

Munsch, S.H., Barber, J.S., Cordell, J.R., Kiffney, P.M., Sanderson, B.L. and Toft, J.D., 2021. Small invertebrates in bivalve-cultivated and unmodified habitats of nearshore ecosystems. Hydrobiologia, 848: 1249-1265.

O'Donnell, J. L., Kelly, R. P., Shelton, A. O., Samhouri, J. F., Lowell, N. C., & Williams, G. D. 2017. Spatial distribution of environmental DNA in a nearshore marine habitat. PeerJ 5: e3044.

Okey, T. A., & Pauly, D. 1999. A mass-balanced model of trophic flows in Prince William Sound: de-compartmentalizing ecosystem knowledge. Ecosystem approaches for fisheries management 16: 621-635.

Oliver, E. C., Donat, M. G., Burrows, M. T., Moore, P. J., Smale, D. A., Alexander, L. V., ... & Wernberg, T. 2018. Longer and more frequent marine heatwaves over the past century. Nature communications 9(1): 1-12.

Orr, J.C., Epitalon, J.-M., Dickson, A.G., Gattuso, J.P., 2018. Routine uncertainty propagation for the marine carbon dioxide system. Marine Chemistry 207: 84-107.

Parkins C, Smolowitz R, and Hopkins N. 2016. Determining the Catch Efficiency of a Cable Sorting Grid in the Summer Flounder Trawl Fishery. [Final Report; 52 p.] NOAA NMFS Contract No. EE-133F-15-SE-1415.

Peet RK. 1974. The measurement of species diversity. Annual Review of Ecology, Evolution, and Systematics 5(1): 285–307.

Pemberton, D. 1996. Port Lincoln Tuna Farms, Dolphins, Seals, Sharks and Seabirds. Unpublished report to Tuna Boat Owners Association of Australasia and Primary Industries South Australia. 8 pp. Parks and Wildlife Service, Tasmania: Hobart.

Pezy, J. P., Raoux, A., & Dauvin, J. C. 2020. An ecosystem approach for studying the impact of offshore wind farms: a French case study. ICES Journal of Marine Science 77(3): 1238-1246.

Pinchuk, A.I., Eisner, L.B. 2017. Spatial heterogeneity in zooplankton summer distribution in the eastern Chukchi Sea in 2012-2013 as a result of large-scale interactions of water masses. Deep Sea Research II 135: 27-39.

Plumlee, J. D., Dance, K. M., Dance, M. A., Rooker, J. R., TinHan, T. C., Shipley, J. B., & Wells, R. J. 2020. Fish assemblages associated with artificial reefs assessed using multiple gear types in the northwest Gulf of Mexico. Bulletin of Marine Science 96(4): 655-678.

Pont, D., Rocle, M., Valentini, A., Civade, R., Jean, P., Maire, A., ... & Dejean, T. 2018. Environmental DNA reveals quantitative patterns of fish biodiversity in large rivers despite its downstream transportation. Scientific Reports 8(1): 1-13.

Price, C.S., E. Keane, D. Morin, C. Vaccaro, D. Bean, and J.A. Morris, Jr. 2016. Protected Species and Longline Mussel Aquaculture Interactions. NOAA Technical Memorandum NOS NCCOS 211. 85 pp.

Prym-Ham, C. 2019. Understanding aquatic farming ADF&G permitting. Presented at Kodiak Regional Mariculture Conference, Kodiak, AK. Retrieved from https://www.adfg.alaska.gov/static/fishing/PDFs/aquaticfarming/2019_understanding_aquatic_farming.pdf

Pring-Ham, C. K. 2020. Alaska Fish and Game aquatic farming permitted operations status report. Alaska Shellfish Growers Association Conference, Ketchikan, AK. https://www.adfg.alaska.gov/static/fishing/PDFs/aquaticfarming/2020_af_permitted_op_status_report.pdf

R Core Team. 2018. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. https://www.R-project.org.

Ralph, P.J. and R. Gademann. 2005. Rapid light curves: A powerful tool to assess photosynthetic activity. Aquatic Botany 82(3): 222-237.

Rand, P.S. and R.E. Thorne. 2018. Expanded adult herring surveys. *Exxon Valdez* Long-Term Herring Research and Monitoring Program Final Report (*Exxon Valdez* Oil Spill Trustee Council Project 16120111-E). *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

Rasmussen, B., Josefson, A.B. 2002. Consistent estimates for the residence time of micro-tidal estuaries. Estuarine, Coastal and Shelf Science 54: 65-73.

Riebesell, U., Fabry, V.J., Hansson, L., Gattuso, J.-P., 2010. Guide to best practices for ocean acidification research and data reporting. Publications Office of the European Union Luxembourg.

Roque D'Orbcastel, E., E. Boudin, M. Li, F. Carcaillet, and E. Fouilland. 2019. Fish, Algae, and Oysters: The Winning Trio in Aquaculture. Frontiers in Young Minds. 7: 131. https://doi.org/10.3389/frym.2019.00131

Rowe, A.G., Iken, K., Blanchard, A.L., O'Brien, D.M., Døving Osvik, R., Uradnikova, M. and Wooller, M.J., 2019. Sources of primary production to Arctic bivalves identified using amino acid stable carbon isotope fingerprinting. Isotopes in Environmental and Health Studies 55(4): 366-384.

Schaefer, A., M.A. Bishop, and R. Thorne. 2020. Marine bird response to forage fish during winter in subarctic bays. Fisheries Oceanography 29: 297-308.

Shahrestani, S., Bi, H., Lyubchich, V., & Boswell, K. M. 2017. Detecting a nearshore fish parade using the adaptive resolution imaging sonar (ARIS): An automated procedure for data analysis. Fisheries Research 191: 190-199.

Shi, H., W. Zheng, X. Zhang, M. Zhu, D. Ding D. 2013. Ecological–economic assessment of monoculture and integrated multi-trophic aquaculture in Sanggou Bay of China. Aquaculture 410: 172-178.

Siedlecki, S.A., Pilcher, D.J., Hermann, A.J., Coyle, K., Mathis, J., 2017. The importance of freshwater to spatial variability of aragonite saturation state in the Gulf of Alaska. Journal of Geophysical Research: Oceans 122: 8482-8502.

Slotte, A., Hansen, K., Dalen, J., & Ona, E. 2004. Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. Fisheries Research 67(2): 143-150.

Stekoll, M.S., 2019. The seaweed resources of Alaska. Botanica Marina 62 (3): 227-235. https://doi.org/10.1515/bot-2018-0064

Stickney, R.R. 2013. Polyculture in Aquaculture. In Sustainable Food Production (Christou P., R.Savin, B. Costa-Pierce, I Misztal, and C.B.A.Whitelaw, editors). Springer, New York. http://doi.org/10.1007/978-1-4614-5797-8_176

Stocking, J., M.A. Bishop, and A. Arab. 2018. Spatio-temporal distributions of piscivorous birds in a subarctic sound during the non-breeding season. Deep-Sea Research Part II 147: 138-147.

Sukkhown, P., T. Pirak, P. Chonpracha, R. Ardoin, and W. Prinyawiwatkul. 2019. Seafood flavor perception, liking, emotion, and purchase intent of coated peanuts as affected by coating color and hydrolyzed squid peptide powder. Journal of Food Science 84(6): 1570-1576.

Sward, D., Monk, J., & Barrett, N. 2017. A systematic review of remotely operated vehicle surveys for visually assessing fish assemblages. Frontiers in Marine Science 6: 134.

Tan K., Ma H., Li S., Zheng H. 2020. Bivalves as future source of sustainable natural omega-3 polyunsaturated fatty acids. Food Chem 311: 125907.

The Nature Conservancy. 2017. The Aquaculture Opportunity: Can the sector grow to provide seafood and jobs in harmony with the ocean? https://www.nature.org/en-us/what-we-do/our-insights/perspectives/the-aquaculture-opportunity/

Thomas, G. L., & Thorne, R. E. 2003. Acoustical-optical assessment of Pacific herring and their predator assemblage in Prince William Sound, Alaska. Aquatic Living Resources 16(3): 247-253.

Thome, R. E. 1971: Investigations into the relation between integrated echo voltage and fish density. Journal of the Fisheries Research Board of Canada 28: 1269-1273.

Thorne, R. E. 1983. Assessment of population abundance by echo integration. In Proc. Symp. On Assessment of Micronekton. Biol. Ocean. J (Vol. 2, pp. 253-262).

Thorne, R.E. 2010. Trends in adult and juvenile herring distribution and abundance in Prince William Sound. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 070830). Prince William Sound Science Center, Cordova, AK.

Tseng, C.K. 1962. Cultivation of *Laminaria japonica* in China. In Manual of Haidai (*Laminaria japonica* Aresch.) cultivation (Tseng, C.K., and C.Y Wu, editors). Science Press, Beijing, China. pp. 99-112.

Uppström, L., 1974. The boron/chlorinity ratio of deep-sea water from the Pacific Ocean. Deep Sea Research 21: 161-162.

USFWS. 2007. North Pacific pelagic seabird observer program observer's manual, inshore/small vessel version, November 2007. U.S. Fish and Wildlife Service, Migratory Bird Management Nongame Program, Anchorage, Alaska. Unpublished protocol manual, 25 pp.

Usher R. 2018. Bottom-Set Gillnet Comparative Gear Study to Reduce Sea Turtle Bycatch. [Final Report; 52 p.] NOAA NMFS Contract No. EA133F-14-SE-3694.

Vilas, D., Coll, M., Corrales, X., Steenbeek, J., Piroddi, C., Calò, A., ... & Claudet, J. 2020. The effects of marine protected areas on ecosystem recovery and fisheries using a comparative modelling approach. Aquatic Conservation: Marine and Freshwater Ecosystems 30(10): 1885-1901.

Villasante, S., Arreguín-Sánchez, F., Heymans, J. J., Libralato, S., Piroddi, C., Christensen, V., & Coll, M. 2016. Modelling marine ecosystems using the Ecopath with Ecosim food web approach: new insights to address complex dynamics after 30 years of developments. Ecological Modelling 331: 1-4.

Visch, W., Kononets, M., Hall, P. O., Nylund, G. M., & Pavia, H. 2020. Environmental impact of kelp (*Saccharina latissima*) aquaculture. Marine Pollution Bulletin 155: 110962.

Wanninkhof, R., 2014. Relationship between wind speed and gas exchange over the ocean revisited. Limnology and Oceanography: Methods 12: 351-362.

Wentworth, C.K.,1922. A scale of grade and class terms for clastic sediments. The Journal of Geology 30: 377-392.

Wilborn, R.E., Rooper, C.N., Goddard, P., Williams, K., Towler, R., 2020. A novel design for sampling benthic zooplankton communities in disparate Gulf of Alaska habitats using an autonomous deep-water plankton pump. Journal of Plankton Research 42(4): 457-466.

Wood, S. N. 2006. Generalized Additive Models: An Introduction with R. Boca Raton, FL: Chapman Hall/CRC.

Xiao, X., Agustí, S., Yu, Y., Huang, Y., Chen, W., Hu, J., Li, C., Li, K., Wei, F., Lu, Y., 2021. Seaweed farms provide refugia from ocean acidification. Science of The Total Environment: 145192.

Xu, M., Qi, L., Zhang, L. B., Zhang, T., Yang, H. S., & Zhang, Y. L. 2019. Ecosystem attributes of trophic models before and after construction of artificial oyster reefs using Ecopath. Aquaculture Environment Interactions 11: 111-127.

Yang, B., Gao, X., Zhao, J., Liu, Y., Lui, H. K., Huang, T. H., ... & Xing, Q. 2021. Massive shellfish farming might accelerate coastal acidification: A case study on carbonate system dynamics in a bay scallop (*Argopecten irradians*) farming area, North Yellow Sea. Science of The Total Environment: 149214.

Yin, X., Arias-Pérez, A., Kitapci, T.H., Hedgecock, D., 2020. High-Density Linkage Maps Based on Genotyping-by-Sequencing (GBS) Confirm a Chromosome-Level Genome Assembly and Reveal Variation in Recombination Rate for the Pacific Oyster *Crassostrea gigas*. G3: Genes, Genomes, Genetics 10: 4691-4705.

Yu, H., Y. Zhang, J. Zhao, and H. Tian. 2018. Taste characteristics of Chinese bayberry juice characterized by sensory evaluation, chromatography analysis, and an electronic tongue. Journal of Food Science and Technology 55(5): 1624–1631.

Yu, R. and P.S. Leung. 2005. Optimal harvesting strategies for a multi-pond and multi-cycle shrimp operation: a practical network model. Mathematics and Computers in Simulation, 68(4): 339-354.

Yu, R. and P.S. Leung. 2006. Optimal partial harvesting schedule for aquaculture operations. Marine Resource Economics, 21(3): 301-315.

Zenone, A. M., Burkepile, D. E., & Boswell, K. M. 2017. A comparison of diver vs. acoustic methodologies for surveying fishes in a shallow water coral reef ecosystem. Fisheries Research 189: 62-66.

Zucker, D.A. and J.L. Anderson. 1999. A dynamic, stochastic model of a land-based summer flounder *Paralichthys dentatus* aquaculture firm. Journal of the World Aquaculture Society 30(2): 219-235.

Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., Smith, G.M. 2009. Mixed effects models and extensions in ecology with R. New York, Springer.

Zydelis, R., D. Esler, W. S. Boyd, D. L. Lacroix, and M. Kirk. 2006. Habitat use by wintering surf and white-winged scoters: effects of environmental attributes and shellfish aquaculture. The Journal of Wildlife Management 70: 1754-1762.

10. PROJECT PERSONNEL

INFORMATION ARCHITECT, CEO
ROBERT BOCHENEK

Axiom Data Science, LLC
1016 W 6th Ave Anchorage, AK 99501
Phone: 907.230.0304 Email: rob@axiomdatascience.com

RELEVANT PROFESSIONAL EXPERIENCE

2012 – Present	Develop and maintain AOOS Data Assembly Center, CeNCOOS Data Assembly Center, SECOORA Data Assembly Center, IOOS Environmental Sensor Map, Marine Biodiversity Observation Network Portal, Animal Telemetry Data Assembly Center, and other association products
2012 – Present	Funded under the NOAA High Performance Computing program for exploratory research in applying HPC concepts to serving and visualizing gridded multidimensional models and observational data sets
2011 – Present	Member of the IOOS Sensor Observation Service Standardization Committee
2010 – Present	Member of the Alaska Data integration Working Group (ADIWG) focused on developing frameworks for interchange of scientific information across Alaskan Agencies.
2008 – 2010	Development of the Prince William Sound Data Portal, a tool for scientists, educators and the public to visualize four-dimensional fisheries data

Professional Positions

2019- Present	Cyberinfrastructure Lead, National Science Foundation, Ocean Observatories Initiative
2018– Present	Technical Lead for Office of Naval Research Animal Telemetry Network DAC
2017– Present	Information Manager, National Science Foundation, North Gulf of Alaska LTER Site
2015– Present	Technical Lead, Southeast Coastal Ocean Observing Regional Association, Charleston, SC
2013 – Present	Technical Lead, Central and Northern California Ocean Observing System, Moss Landing, CA
2010 – Present	Technical Lead, Alaska Ocean Observing System, Anchorage, AK
2006 – Present	Information Architect and CEO, Axiom Data Science, Anchorage, AK
2003 – 2006	Data Systems Manager, *Exxon Valdez* Oil Spill Trustee Council (EVOSTC), Anchorage, AK
2001 – 2002	Analyst Programmer, Alaska Department of Fish & Game, Anchorage, AK

RELEVANT PUBLICATIONS & PRODUCTS

Bochenek, R.B., McCammon, M., Stone, B.J. (2019). AOOS Ocean Data Explorer. https://portal.aoos.org; 10+ regional data portals: http://www.aoos.org/aoos-data-resources/.

Bochenek R.B., Vance, T., Stone, B.J. (2019). IOOS Environmental Sensor Map. https://sensors.ioos.us/

Bochenek R.B., Canonico, G.., Stone, B.J. (2019). Marine Biodiversity Observation Network (MBON) and Arctic MBON. https://mbon.ioos.us/

Lopez, J., Austin, J., Koeppen, W. and **Bochenek, R.B.** (2018). AIS Vessel Traffic Data Products and Arctic Oil Spill Risk Assessment (OSRA) Products. http://ais.axds.co. and https://osra.axds.co/.

Turner, C. and **Bochenek, R.** (2017). "Cyberinfrastructure to support data management," in OCEANS Anchorage, 2017., 2017, Anchorage, AK, [Online]. Available: http://ieeexplore.ieee.org/document/8232392/
Bochenek, R.B., R. Martin (2017), Research Workspace. https://researchworkspace.com.
Bochenek, R.B., Baker, B. (2019). North Pacific Research Board. Project Search & Database. http://projects.nprb.org

EDUCATION

University of Michigan Ann Arbor, MI Aerospace Engineering, B.S.E. 2001

COLLABORATIONS

Anderson, Clarissa (Scripps Institution of Oceanography); Arp, Christopher (University of Alaska Fairbanks); Baker, Matthew (North Pacific Research Boar (NPRB)); Bailey, Kathleen (Integrated Ocean Observing System (IOOS)); Beaulieu, Stace (Woods Hole Oceanographic Institute (WHOI)); Biddle, Matthew, (IOOS); Bresnahan, Phillip (Scripps Institution of Oceanography); Broderson, Dayne (University of Alaska, Alaska Center for Energy and Power); Burger, Eugene (NOAA Pacific Marine Environmental Laboratory (PMEL)); Canonico, Gabrielle (IOOS); Chavez, Fransisco (Monterey Bay Aquarium Research Institute); Crowley, Heather (Bureau Ocean Energy Management); Daniel, Patrick (Central and Northern California Ocean Observing System (CeNCOOS)); Danielson, Seth (University of Alaska Fairbanks (UAF)); Davis, Nolan (LEIDOS); Decker, Julie (Alaska Fisheries Development Fund); Dickson, Danielle (NPRB); Dorton, Jennifer (Southeast Coastal and Ocean Observing Regional Association (SECOORA)); Dugan, Darcy (AOOS); Glastein, Jeffrey (WHOI); Goldmann, Maxwell, Audubon Alaska; Harper, Alex (CeNCOOS); Hatch, Leila (NOAA); Hernandez, Debra (SECOORA); Hoffman, Katrina (Prince William Sound Science Center); Holderied, Kris (NOAA National Centers for Coastal Ocean Science); Hopcroft, Russell (UAF); Howard, Katherine (Alaska Department of Fish and Game); Iken, Katrin (UAF); Janzen, Carol (AOOS); Jones, Benjamin (UAF); Jones, Matthew (National Center for Ecological Analysis and Synthesis); Jones, Tahzay (National Park Service); Kaczmarek, Michael (Carnival Corporation); Kasper, Jeremy (UAF); Kee, Randy (ADAC-University of Alaska, Anchorage); Kent, Holly (AOOS); Konar, Brenda (UAF); Knutson, David (Olgoonik Corporation); Lindeberg, Mandy (NOAA National Marine Fisheries Service); Merkel, Heike (University of Alaska, Alaska Center for Energy and Power); McCammon, Molly (AOOS); Mellish, Joann (NPRB); Morse, Laura (ORSTED); Migurra, Mandy (NOAA National Marine Fisheries Service); Mueter, Franz (UAF); Muller-Karger, Frank (University of Florida); Mundy, Phillip (Alaska Fisheries Science Center); O'Brien, Margaret (University of California Santa Barbara); Palenski, Lynn (NPRB); Pegau, Scott, Oil Spill Recovery Institute

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EDUCATION

Doctor of Philosophy, University of Victoria, School of Earth and Ocean Sciences (1999-2003)
Thesis: "Overwintering ecology of *Neocalanus plumchrus*"
Master of Science, Biology, Dalhousie University (1996-1998)
Thesis: "Reproduction of Calanus finmarchicus in the western North Atlantic: fecundity and hatching success"
Bachelor of Science (Hons), Biology, University of Toronto (1991-1996)
Thesis: "Simulation and bioenergetic modeling of Walleye (Stizostedion v. vitreum) populations"

APPOINTMENTS

2020 – present	Chief Science Officer, Prince William Sound Science Center
2007 – present	Oceanographer, Prince William Sound Science Center
2010 – present	Affiliate faculty, University of Alaska Anchorage
2004-2006	Post-doctoral researcher, University of Hamburg, Germany

RECENT RELEVANT PUBLICATIONS

Arimitsu, M., Piatt, J., Hatch, S., Suryan, R.M., Batten, S., Bishop, MA, Campbell, R.W., Coletti, H., Cushing, D., Gorman, K., Hopcroft, R., Kuletz, K.J., Marsteller, C.M., McKinstry, C., McGowan, D., Moran, J., Pegau, W.S., Schaefer, A., Schoen, S., Straley, J. and V.R. von Biela. 2021. Heatwave-induced synchrony within forage fish portfolio disrupts energy flow to top pelagic predators. Global Change Biol, Accepted 1/2021.

Suryan, R.M., Arimitsu,M.L., Coletti, H.A., Hopcroft, R.R., Lindeberg, M.R., Barbeaux, S.J., Batten, S.D., Burt, W.J., Bishop, MA, Bodkin, J.L., Brenner, R., Campbell, R.W., Cushing, D.A., Danielson, S.L., Dorn, M.W., Drummond, B., Esler,D., Gelatt, T., Hanselman, D.H., Hatch, S.A., Haught, S., Holderied, K., Iken, K., Irons, D.B., Kettle, A., Kimmel, D.G., Konar, B., Kuletz, K.J., Laurel, B.J., Maniscalco, J.M., Matkin, C., MckKinstry, C.A.E., Monson, D.H., Moran, J.R., Olsen,D., Palsson, W.A., Pegau, W.S., Piatt, J.F., Rogers, L.A., Rojek, N., Schaefer, A., Spies,I.B., Straley, J.M., Strom, S.L., Sweeney, K.L., Szymkowiak, M., Weitzman, B.P., Yasumiishi, E.M. and S.G. Zador. 2021. Ecosystem response persists after a prolonged marine heatwave. Sci. Rep. Accepted 1/2021.Campbell, R.W., Roberts, P.L. and J. Jaffe. 2020. The Prince William Sound Plankton Camera: a profiling in situ observatory of plankton and particulates. ICES J. Mar. Sci. doi:10.1093/icesjms/fsaa029.

Tomco, P.L., Zulueta, R.C., Miller, L.C., Zito, P.A., Campbell, R.W. and J.M. Welker. 2019. DOC export is exceeded by C fixation in May Creek: A late successional watershed of the Copper River Basin, Alaska. PLoS ONE 14(11): e0225271. https://doi.org/10.1371/journal.pone.0225271

Campbell, R.W. 2018. Hydrographic trends in Prince William Sound, Alaska, 1960–2016. Deep Sea Res. doi: 10.1016/j.dsr2.2017.08.014

McKinstry, C.A.E., and R.W. Campbell. 2018. Seasonal variation of zooplankton abundance and community structure in Prince William Sound, Alaska, 2009–2016. Deep Sea Res. doi: 10.1016/j.dsr2.2017.08.016

Crusius, J., Schroth, A.W., Resing, J.A., Cullen, J. and R.W. Campbell. 2017. Seasonal and spatial variabilities in the northern Gulf of Alaska surface water iron concentrations driven by shelf sediment resuspension, glacial meltwater, a Yakutat eddy, and dust. Global Biogeochemical Cycles. Doi: 10.1002/2016GB005493

Batten, S.D., Moffitt, S., Pegau, W.S. and R. Campbell. 2016. Plankton indices explain interannual variability in Prince William Sound herring first year growth. Fisheries Oceanography 25:420-434. doi: 10.1111/fog.12162

Schroth, A.W., Crusius, J., Hoyer, I. and R. Campbell. 2013. Estuarine removal of glacial iron and implications for iron fluxes to the ocean. Geophysical Research Letters. doi: 10.1002/2014GL060199.

OTHER PUBLICATIONS

Kattner, G., Hagen, W., Lee, R.F., Campbell, R.W., Deibel, D., Falk-Petersen, S., Graeve, M., Hansen, B.W., Hirche, H.J., Jonasdottir, S.H., Madsen, M.L., Mayzaud, P., Müller-Navarra, D., Nichols, P., Paffenhöffer, G.A., Pond, D., Saito, H., Stübing, D., and P. Virtue. 2007. Perspectives on zooplankton lipids. Can. J. Fish. Aquat. Sci. 64:1628-1639.

Irigoien, X., Harris, R.P., Verheye, H.M., Joly, P., Runge, J.A., Starr, M. Pond, D., Campbell, R.W., Shreeve, R., Ward, P., Smith, A.N., Dam, H.G., Napp, J., Peterson, W., Tirelli, V., Koski, M., Smith, T., Harbour, D., Strom, S. and R. Davidson. 2002. Copepod Hatching Success Rate in Marine Ecosystems with High Diatom Concentrations - the Paradox of Diatom-Copepod Interactions Revisited. Nature. 419:387-389.

Mackas, D., et. al. 2013. Zooplankton time series from the Strait of Georgia: Results from year-round sampling at deep water locations, 1990–2010. Progress in Oceanography. 115:129-159.

Campbell, R.W and J.F. Dower. 2008. Life history and depth distribution of Neocalanus plumchrus in the Strait of Georgia. J. Plankton Res. 30:7-20.

RECENT COLLABORATORS (EXCLUSIVE OF CO-AUTHORS ALREADY LISTED ABOVE)

Causey, Doug (UAA); Doroff, Angela (UAA); Gassó , Santiago (NASA); Gorman, Kristin (UAF); Heintz, Ron (NOAA, ret.); Rand, Pete (PWSSC); Sewall, Fletcher (NOAA); Sorum, Alan (PWSRCAC); Thomas, Andrew (U Maine); West, Mick (Ga. Tech)

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EDUCATION

2011 Ph.D, Memorial University of Newfoundland, St. John's, Newfoundland, Canada
2001 Masters, Aquaculture, Memorial University of Newfoundland, St. John's Newfoundland, Canada

SELECT PROFESSIONAL EXPERIENCE

2020-Current **Research Ecologist -**Alaska Fisheries Science Center (AFSC), National Oceanic and Atmospheric Administration (NOAA), Hatfield Marine Science Center, Newport, OR, USA.
2020-2026 **Courtesy Faculty -** College of Earth, Ocean and Atmospheric Sciences, Oregon State University, Hatfield Marine Science Center, Newport, OR, USA.
2019-2020 **Associate Professor (Senior Research) -** College of Earth, Ocean and Atmospheric Sciences, Oregon State University, Hatfield Marine Science Center, Newport, OR, USA.
2013-2019 **Assistant Professor (Senior Research) -** College of Earth, Ocean and Atmospheric Sciences, Oregon State University, Hatfield Marine Science Center, Newport, OR, USA.
2011-2013 **Research Associate -** Cooperative Institute for Marine Resources Studies, Oregon State University, Hatfield Marine Science Center, Newport, OR, USA
2010-2011 **Post-Doctoral Fellow -** Marine Ecology, Ocean Sciences Centre, Memorial University of Newfoundland, St. John's, NL, Canada
2004-2011 **Graduate Research/Teaching Assistant,** Ph.D. program, Marine Ecology, Ocean Sciences Centre, Memorial University of Newfoundland, St. John's, NL, Canada (Family leave from program 2005 to 2009)

SELECT PUBLICATIONS

Copeman, L., Spencer, M., Heintz, R. et al. (2020) Ontogenetic patterns in lipid and fatty acid biomarkers of juvenile polar cod (*Boreogadus saida*) and saffron cod (*Eleginus gracilis*) from across the Alaska Arctic. Polar Biol. https://doi.org/10.1007/s00300-020-02648-9

Copeman LA, Ryer C, Spencer M, Otmar M, Iseri P. Sremba A, Parrish C, Wells J (2018) Flux of diatom production to benthos controls habitat quality and juvenile Tanner crab growth in shallow water embayments around Kodiak Island Alaska. *Marine Ecology Progress Series* 597:161–178. https://doi.org/10.3354/meps12621

Koenker B, **Copeman LA**, Laurel B (2018) Impacts of temperature and food availability on the condition and lipid storage of larval Arctic cod and walleye pollock. *ICES journal of Marine Science*, 75(7): 2370-2385. http://doi.org/10.1093/icesjms/fsy052.

Laurel B, **Copeman LA**, Spencer M, Iseri P (2018) Comparative effects of temperature on eggs and yolk-sac larvae of Arctic cod (*Boreogadus saida*) and walleye pollock (*Gadus chalcogrammus*). *ICES Journal of Marine Science* 75(7): 2403-2412. http://doi:10.1093/icesjms/fsy042.

Koenker B, Laurel B, **Copeman LA**, Ciannelli L (2018) Effects of temperature and food availability on the survival and growth of larval Arctic cod (*Boreogadus saida*) and walleye pollock. *ICES Journal of Marine Science* 75(7): 2386-2402. https://doi.org/10.1093/icesjms/fsy062.

Copeman LA, Laurel BJ, Spencer M, Sremba A (2017) Temperature impacts on lipid allocation among gadid species at the Pacific Arctic–Boreal interface: an experimental laboratory approach. *Marine Ecology Progress Series* 566:183–198.

Laurel BJ, **Copeman LA**, Spencer M, Iseri P (2017) Temperature-dependent growth as a function of size and age in juvenile Arctic cod (*Boreogadus saida*). *ICES Journal of Marine Science* 74:1614-1621.

Copeman, L. Daly, B., Eckert, G., Swingle, J. (2014). Storage and utilization of lipid classes and fatty acids during the early ontogeny of blue king crab, *Paralithodes platypus*. *Aquaculture*, 424–425: 86-94. https://doi.org/10.1016/j.aquaculture.2013.12.025.

Copeman LA, Laurel BJ, Sremba A, Klinck K, Heintz R, Vollenweider J, Boswell K (2016) Ontogenetic variability in the lipid content of saffron Cod (*Eleginus gracilis)* from the Western Arctic and Northern Chukchi. *Polar Biology* 39 (6): 1109–1126.

Copeman LA, Laurel BJ, Parrish CC (2013) Effect of temperature and tissue type on fatty acid signatures of two species of North Pacific juvenile gadids: a laboratory feeding study. *Journal of Experimental Marine Biology and Ecology* 448: 188-196.

Copeman, L., Stoner, W. Ottmar, M, Daly, B., Parrish, C., Eckert, G. (2012). Total Lipids, Lipid Classes, and Fatty Acids of Newly Settled Red King Crab (*Paralithodes camtschaticus*): Comparison of Hatchery-Cultured and Wild Crabs. *Journal of Shellfish Research*, 31(1), 153-165.

Copeman LA, Laurel BJ (2010) Experimental evidence of fatty acid limited growth and survival in Pacific cod (*Gadus macrocephalus*) larvae. *Marine Ecology Progress Series* 412:259-272.

Copeman LA, Parrish CC, Gregory RS, Jamieson, RE, Well J, Whiticar MJ (2009) Fatty acid biomarkers in coldwater eelgrass meadows: elevated terrestrial input to the food web of age-0 Atlantic cod, *Gadus morhua*. *Marine Ecology Progress Series* 386: 237-251.

Copeman LA, Parrish CC, Gregory RS, Wells J (2008) Decreased lipid storage in juvenile Atlantic cod (*Gadus morhua*) during settlement in cold-water eelgrass habitat. *Mar Biol* 154(5): 823-832.

Copeman, L., Parrish, C. Brown, J.A., Harel, M. (2002). Effects of docosahexaenoic, eicosapentaenoic, and arachidonic acids on the early growth, survival, lipid composition and pigmentation of yellowtail flounder (*Limanda ferruginea*): a live food enrichment experiment, *Aquaculture*, 210: 285-304. https://doi.org/10.1016/S0044-8486(01)00849-3.

COLLABORATORS

Allan, Sarah (NOAA), Beder, Asia (UAF), Bosley, Katelyn (OSU), Bosley, Keith (NOAA), Boyd, Daryle (NOAA), Cameron, James (NOAA) Ciannelli, Lorenzo (OSU), Claiborne, Andrew (WDFW), Daly, Elizabeth (OSU), Daniels, Kamilya (Savannah State University), Danielson, Seth (UAF), Donald, Carey (Institute of Marine Research, Norway), Du, Xiuning (OSU), Dumbauld, Brett (USDA), Eckert, Ginny (UAF), Feinberg, Leah (Cooperative Institute for Marine Resources Studies), Fisher, Jennifer (Cooperative Institute for Marine Resources Studies), French, Barbara (NOAA), Haines, Scott (NOAA), Heinz, Ron (NOAA), Hubbard, Kalyn (OSU), Hurst, Thomas (NOAA), Hutchinson, Greg (NOAA), Incardona, John (NOAA), Iseri, Paul (NOAA), Pinchuk, Alexei (UAF), Teel, David (NOAA), Thomas (NOAA), Koenker, Brittany (OSU), Laurel, Benjamin (NOAA), Linbo, Tiffany (NOAA), Litz, Marisa (OSU, WDFW), Logerwell, Libby (NOAA), Meier, Sonnich (Institute of Marine Research, Norway), Menkel, Jennifer (Cooperative Institute for Marine Resources Studies), Meredith, Summer (OSU), Miller, Jessica (OSU), Morgan, Cheryl (OSU), Nordtug, Trond (SINTEF Ocean), Ottmar, Michele (NOAA), Parrish, Christopher (St. Johns Memorial University), Peterson, William (NOAA), Ryer, Clifford (NOAA), Scholz, Nathaniel (NOAA), Shaw, Tracy (Cooperative Institute for Marine Resources Studies), Sousa, Leandra (North Slope Borough), Spencer, Mara (NOAA), Sremba, Angie (OSU), Stowell, Michelle (OSU), Vollenweider, Johanna (NOAA), Wells, Jeanette (St. Johns Memorial University), Weitkamp, Laurie (NMFS), Ylitalo, Gina (NOAA)

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EDUCATION

2012- 2017 PhD in Integrated Bioscience, The University of Akron (UA), Akron, OH
Thesis titled: "The Interaction of Chemical and Natural Stressors on Cardiovascular Dynamics in Teleost Fish"

2008-2012 B.S. in Biology with Minor in Chemistry, Clarion University (CU), Clarion, PA

PROFESSIONAL

2020-present Postdoctoral Research Associate
Prince William Sound Science Center (PWSSC), Cordova, AK
Supervisor: Mary Anne Bishop, PhD.

2018-2020 National Research Council Postdoctoral Research Associate
NOAA NW Fisheries Science Center, Ecotoxicology Program, Seattle, WA
Supervisor: John Incardona, PhD.

RESEARCH EXPERIENCE

Publications in Preparation

Cypher, A. D., Linbo, T., Cameron, J., Donald, C., Gill, A., Gregg, J., Hershberger, P., Meier, S., Whitehead, A., Scholz, N., Incardona, J. P. Crude oil-induced cardiovascular pathology varies with source population in larval *Clupea pallasi.*

Cypher, A. D., Linbo, T., Cameron, J., Gill, A., Gregg, J., Hershberger, P., Whitehead, A., Meier, S., Copeman, L., Scholz, N., Incardona, J. P. Lipid metabolism and composition through development to juvenile stage in Pacific herring.

Cypher, A. D., Linbo, T., Cameron, J., Gill, A., Gregg, J., Hershberger, P., Whitehead, A., Copeman, L.,Scholz, N., Incardona, J. P. First year overwinter survival and bioenergetics in juvenile *Clupea pallasi* after an embryonic exposure to crude oil.

Refereed Publications

Cypher, A. D., Fetterman, B., Bagatto, B., 2018. Vascular parameters continue to decrease post-exposure with simultaneous, but not individual exposure to BPA and hypoxia in zebrafish larvae. Comp. Bioch. And Phys. Part C 11-16. http://dx.doi.org/10.1016/j.cbpc.2018.02.002

Cypher, A. D., Consiglio, J. C., Bagatto, B., 2017. Hypoxia exacerbates the cardiotoxic effect of the polycyclic aromatic hydrocarbon, phenanthrene in *Danio rerio*. Chemosphere 574-581. https://doi.org/10.1016/j.chemosphere.2017.05.109

Cypher, A. D., Ickes, J. Bagatto, B., 2015. Bisphenol A alters the cardiovascular response to hypoxia in *Danio rerio* embryos. Comp Bioch and Phys Part C 174-175, 39-45. http://dx.doi.org/10.1016/j.cbpc.2015.06.006

Grants Awarded

2019 Oiled Wildlife Care Network ($70,000)
P.I. Alysha Cypher

2019 Prince William Sound Regional Citizens' Advisory Council ($60,000)
P.I. John Incardona

2017 North Pacific Research Board ($208,346)
P.I.s John Incardona and Louise A. Copeman

Professional Collaborations

Brian Bagatto (University of Akron), Mary Anne Bishop (PWSSC), James Cameron (NWFSC), Louise Copeman (Oregon State/AFSC), Carey Donald (Institute of Marine Research, Bergen, Norway), Anthony Gill (UC Davis), Jacob Gregg (USGS), Louisa Harding (WDFW), Paul Hershberger (USGS), John Incardona (NWFSC), Ben Laurel (AFSC), Tiffany L. Linbo (NWFSC), Jenifer McIntyre (WSU Puyallup), Sonnich Meier (Institute of Marine Research, Bergen, Norway), Brad Reynolds (PWSSC), Nathaniel Scholz (NWFSC), Elin Sørhus (Institute of Marine Research, Bergen, Norway), James West (WDFW), Andrew Whitehead (UC Davis), Gina M. Ylitalo (NWFS)

Julie Decker
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Education

- **University of Alaska Southeast: M.P.A.,** concentration in ***Natural Resource Management*** (2013), UAS Ernest Gruening Award recipient for outstanding MPA graduate of the year; Non-degree courses: Multicultural Education (1997)
- **Northwestern University, Evanston: B.A.-** Ad hoc major: ***Ethnomusicology*** (1991-1995)

Select Volunteer Service

- **Alaska Mariculture Task Force,** *Chair* (gubernatorial appointment 2016-current)
- **Certified Seafood Collaborative,** *Board of Directors* (2020-current)
- **Alaska Seafood Marketing Institute,** *Salmon, Technical, & RFM Committees* (2012-2016, 2012-current, 2016-2020)
- **SE Alaska Ocean Cluster,** *Co-Chair* (2011-2015)
- **Alaska Fisheries Development Foundation,** *Board of Directors* (2007-2011)
- **United Fishermen of Alaska,** *Board of Directors* (2006-2020)
- **Southeast Conference,** *Board of Directors, Fisheries Committee Chair, Fisheries Committee* (2005-2008, 2003-2008, 2003-2021)

Select Employment History

Executive Director (Jan., 2014-current); Development Director (2011-2013)
Alaska Fisheries Development Foundation, Wrangell, AK
Duties include Board support, financial management, grant writing & administration, advocacy, managing research & development projects. Focus areas: 100% utilization, product development, increased sustainability, workforce development, & launched ***Alaska Mariculture Initiative*** with vision to grow a $1 billion industry in 30 years; currently chairing the ***Alaska Mariculture Task Force*** established by Administrative Order in 2016.

Coalition Coordinator (Contractor) (2010 – 2012)
United Fishermen of Alaska, National Seafood Marketing Coalition, Juneau, AK
Coordinated initiative to create a new ***national seafood marketing program*** ($100M annually) to market US produced seafood. Helped raise $400K to fund effort, formed coalition of 75+ supporting organizations, developed draft language for bill introduced by Sen. Begich in 2012.

Executive Administrator, VP (2006-2008)
Wrangell Seafoods, Inc., Wrangell, AK
Helped manage $7M re-tooling & expansion project for a mid-sized seafood processor; coordinated public relations; primary staff to attorneys and witness during arbitration against multi-national company.

Executive Director (1998-2006)
Southeast Alaska Regional Dive Fisheries Association, Wrangell, AK

Led 400+ member dive fisheries advocacy NGO. Value of fishery increased from ~$3M to ~$12M annually. Oversaw accounting, grant writing & administration, lobbying, advocacy & project management. Secured $450K+ in grants. Instrumental in passage of 3 bills in AK Legislature.

Commercial Fisherman & Diver (1995-current), Direct Marketer (2005-2010)

Self-employed, F/V McCrea, Wrangell, AK

Business partnership with husband; worked in various commercial fisheries in SE AK; raised our children fishing for salmon in summers (2008-18) onboard family-owned F/V McCrea.

Non-peer-reviewed publications

Decker, Julie. 2012. Steps Toward Energy Efficiency. National Fisherman. May:6.

Decker, Julie. 2014. Preliminary Results of Fishing Vessel Energy Audits. National Fisherman. Feb:6.

Decker, Julie. 2014. AFDF Announces New Mariculture Initiative. Fishermen's News. July:11.

Decker, Julie. 2014. Alaska Mariculture Initiative – Concept Paper. https://www.afdf.org/wp-content/uploads/1a-AMI-Concept-Paper-1.pdf

Decker, Julie. 2015-11-18. Mariculture - Increase the Value of Your Seafood Business. Pacific Seafood Expo. https://www.afdf.org/wp-content/uploads/Mariculture-presentation-at-Pacific-Marine-Expo-by-Julie-Decker-2015-11-18.pdf

Decker, Julie. 2016-11-19. A Farm for Every Fisherman? Diversifying Your Business through Mariculture. https://oceansalaska.org/wp-content/uploads/2016/11/Fish-Expo-Mariculture-Presentation-2016-11-19.pdf

Decker, Julie. 2017. Alaska's Seafood Bounty. National Fisherman. May:8.

Decker, Julie, et al. 2018-03-23. Alaska Mariculture Development Plan. https://www.afdf.org/wp-content/uploads/Alaska-Mariculture-Development-Plan_v2018-06-29_FINAL_digital.pdf

Decker, Julie, et al. 2018. Alaska Mariculture Development Plan – In Brief. https://www.afdf.org/wp-content/uploads/In-Brief-Alaska-Mariculture-Development-Plan-FINAL-ONLINE.pdf

Decker, Julie, et al. 2019-01-30. Presentation to Alaska Senate Resources Committee. *Alaska Mariculture Development Plan and Task Force*.

Decker, Julie, et al. 2019-02-19. Presentation to Alaska Legislature. *Lunch & Learn: Mariculture in Alaska – Challenges, Opportunities and a Plan for Growth*.

Decker, Julie, Moreland, S., Smith, R.. 2019-02-28. Dock Talk: Are We Socially Responsible. National Fisherman. March:2019. https://www.nationalfisherman.com/viewpoints/national-international/dock-talk-are-we-socially-responsible/

Collaborators

Albert, David (The Nature Conservancy); Buckelew, Stacey (Axiom Data Science); Calvin, Jim (McDowell Group); Consenstein, Kate (Rising Tide Communications); Eckert, Ginny (UAF/UAS); Langdon, Chris (Oregon State University); Leach, Frances (United Fishermen of Alaska); Marsh, Tomi (OceansAlaska); Rodrigues, Alyssa (Alaska Manufacturer's Extension Project (MEP) Center); Sannito, Chris (Alaska Sea Grant); Stekoll, Michael (UAF/UAS); Woodrow, Jeremy (Alaska Seafood Marketing Institute); Wyatt, Eric (Blue Starr Oyster Company)

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Professional Preparation:	Dartmouth College, Hanover, NH	Biology B.A. 1990
	University of Florida, Gainesville, FL	Zoology M.S. 1994
	University of California, Santa Barbara, CA	Biology Ph.D. 1999

Appointments:

Director, Alaska Sea Grant, 2020-present

Professor of Fisheries, Fisheries Division, College of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 2014-present

Interim Director, Alaska Sea Grant, August 2019-June 2020 & April-August 2018

Associate Director of Research, Alaska Sea Grant, 2014-2020

Associate Professor of Fisheries, Fisheries Division, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 2008-2014

Associate Professor of Biology, University of Alaska Southeast, with joint appointment to School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 2006-2008

Visiting Professor, Oregon Institute of Marine Biology, University of Oregon, 2006-2007 sabbatical appointment

Assistant Professor of Biology, University of Alaska Southeast, with joint appointment to School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 2000-2006

Related Recent Publications (10):

Raymond, W.W., B.B. Hughes, T.A. Stephens, C.R. Mattson, A.T. Bolwerk, and **G. L. Eckert**. 2021. Testing the generality of sea otter-mediated trophic cascades in seagrass meadows. Oikos. 10.1111/oik.07681

Kaiser, B. A., M. Kourantidou, D. Ahsan, S. Bakanev, A. Burmeister, **G. Eckert**, L. M. Fernandez, H. P. Hong, A. A. Monsalve, D. Mullowney, B. H. Nøstvold, H. Park, E. Poulsen, L. Ravn-Jonsen, C. Siddon, J. H. Sundet, K. Tokunaga, and M. Yamamoto. 2021. Global ecological and economic connections in Arctic and sub-Arctic crab markets. Marine Policy 127:104442. https://doi.org/10.1016/j.marpol.2021.104442

Daly, B., W.C. Long, and **G.L. Eckert**. 2020. Molding the ideal crab: implications of phenotypic plasticity for crustacean stock enhancement. ICES Journal of Marine Science doi:10.1093/icesjms/fsaa043

Raymond, W., M. T. Tinker, B. Benter, M. Kissling, V. Gill, **G.L. Eckert.** 2019. Location specific factors influence patterns and effects of subsistence sea otter harvest in Southeast Alaska. Ecosphere 10(9):e02874 https://doi.org/10.1002/ecs2.2874

Tobin, E.D., C.L. Wallace, C. Crumpton, G. Johnson, **G.L. Eckert**. 2019. Environmental drivers of paralytic shellfish toxin producing *Alexandrium* blooms in a fjord system of Northern Southeast Alaska. Harmful Algae 88: 101659 https://doi.org/10.1016/j.hal.2019.101659

Olson, A.P., C.E. Siddon, **G.L. Eckert**. 2018. Spatial variability in size at maturity of golden king crab (*Lithodes aequispinus*) and implications for fisheries management. Royal Society Open Science **5**: 171802. http://dx.doi.org/10.1098/rsos.171802

Beder, A., L.A. Copeman, **G.L. Eckert**. 2018. The effects of dietary essential fatty acids on the condition, stress response and survival of red king crab larvae. Journal of Crustacean Biology. https://doi.org/10.1093/jcbiol/ruy085

Vandersea, M.W., S.R. Kibler, S.B. Van Sant, P.A. Tester, K. Sullivan, **G.L. Eckert**, C. Camarata, K. Reece, G. Scott, A. Place, K. Holdereid, D. Hondolero, R.W. Litaker. 2017. qPCR assays for *Alexandrium fundyense* and *A. ostenfeldii* (Dinophyceae) identified from Alaskan waters and a review of species-specific *Alexandrium* molecular assays. Phycologia 56(3): 303-320. DOI: 10.2216/16-41.1

Eckert, G.L. 2017. Unexpected circumstance and adventure in the Aleutians uncover trophic cascades. Ecology 98(1):284-285. DOI: 10.1002/ecy.1694

Pinchuk, A.I., H.R. Harvey, **G.L. Eckert**. 2016. Development of biochemical measures of age in the Alaskan red king crab: validation, refinement and initial assessment. Fisheries Research 183:92-98. http://dx.doi.org/10.1016/j.fishres.2016.05.019

Collaborators:

Ahsan, Dewan, University of Southern Denmark
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Poulsen, Edward, Bering Sea Fishery Research Foundation
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Siddon, C., ADFG
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Tester, Patricia A., Ocean Tester
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Education

- Ph.D., Environmental and Natural Resource Economics, University of Rhode Island, 1999.
- M.S., Resource Economics, University of Rhode Island, 1994.
- M.S., Biological Sciences, Florida Institute of Technology, December 1989.
- B.S., Biological Sciences, Florida Institute of Technology, June 1981.

Work Experience

Professor (2017-present), Assoc. Prof. (2005-2017), Asst. Prof (1999-2005) UAF
Trade Representative/Market Specialist, American Seafood Institute (1997-1998)
Independent Seafood Trader (1992-1999)
Research Diver, Florida Institute of Technology (1981-1987)
Commercial and Dive Fishery Diver (1975-1989)

Selected Publications in Refereed Journals

Anvari, M., B. Smith, C. Sannito & **Q.S.W. Fong**. 2018. Characterization of rheological and physicochemical properties of Alaska walleye pollock (*Gadus chalcogrammus*) roe. Journal of Food Science and Technology. 55(9): 3616-3624

Chen, J.Q, M.C. Haws, **Q.S.W. Fong**, & P.S. Leung. 2017. Locally-Grown Oysters in Hawaii: Chef Preference and Local Premium? Journal of the World Aquaculture Society 48(6): 972-980.

Chen, J.Q., M.C. Haws, **Q.S.W. Fong**, & P.S. Leung. 2017. Economic feasibility of producing oysters using a small-scale Hawaiian fishpond model. Aquaculture Reports 5 (2017): 41-51.

Lee, J., **Q. Fong**, J.W. Park. 2016. Effects of pre-freezing treatments on the quality of Alaska pollock fillets subjected to freezing/thawing. Food Bioscience 16 (2016): 50-55.

Xu, P., **Q. Fong**, A. Bersamin, and B. Izumi. 2015. Fisheries-to-School in Alaska: A Food Service Directors' Perspective. International Journal of Business and Management 10 (2): 142-149.

Xu, P., **Q. Fong,** C., Zeng, Y.C., Lone., T., Liu, Y.Y. 2012. Chinese Consumers' Willingness-to-Pay for Green- and Eco- Labeled Seafood. Food Control, 28: 74-82.

Oliveira, A.C.M., P.J. Bechtel, D.X. Nguyen, L. Gurer, C.A. Crapo, **Q. Fong**, and R. RaLonde. 2011. Chemical composition and texture of commercial Geoduck clams (*Panopea abrupta),*harvested in Alaska. Journal of Shellfish Research 30(3): 761-769

Crapo CA, A.C.M. Oliveira, D.X. Nguyen, P.J. Bechtel PJ, **Q.S.W. Fong**. 2010. Development of a method to produce freeze dried cubes from three Pacific salmon species. J. Food Sci. 75(5):E269-E275.

Codero, F.J.M. **Q.S.W. Fong**, and M.C. Haws. 2009. Marketing Extension and Outreach in Sinaloa, Mexico: A Preliminary Analysis of Preferences for Oysters. Marine Resource Economics 24(1): 89-95.

Oliveira, A.C.M., B. Himelbloom, C.A. Crapo, C. Vorholt, **Q. S.W. Fong**, and R. RaLonde. 2006. Quality of Alaskan Maricultured Oysters (*Crassostrea gigas*): a one-year survey. Journal of Food Science 71(9): 532-543.

Herrmann, M., X. Pei, C. Dong, **Q.S.W. Fong**, and C. Crapo. 2006. Rating Alaska salmon protein concentrate in China. Journal of Food Products Marketing 12(1): 57-85.

Fong, Q.S.W., S. Ellis, and M. Haws. 2005. Economic feasibility of small-scale black lipped pearl oyster (*Pinctada margaretifera*) pearl farming in the Central Pacific. Journal of Aquaculture Economics and

Management 9(3): 347-368.

Collaborators

Aarattuthodiyil, Suja (Mississippi State University), Asche, Frank (University of Florida), Beer, Ken (The Fishery, Inc.), Bradt, Gabriella (New Hampshire Sea Grant), Chambers, Michael (New Hampshire Sea Grant), Clemetson, Antoinette (New York Sea Grant), Concepcion, Anoushka (Connecticut Sea Grant), Cuevas Uribe, Rafael (Humboldt State University), Culver, Carrie (California Sea Grant), Decker, Julie (Alaska Fisheries Development Foundation), Dey, Madan (Texas State University), Dewitt, Christina (Oregon State University), Engle, Carole (Independent Consultant), Gardner, Luke (California Sea Grant), Good, Melissa (Alaska Sea Grant), Hanson, Terry (Auburn University) Haws, Maria (University of Hawaii Hilo), Karunakaran, Ganesh (Mississippi State University), Kotowicz, Dawn (Rhode Island Sea Grant), Quagrainie, Kwamena (Purdue University), Kwon, Jung (Oregon State University), Leung, PingSun (University of Hawa Manoa), Marsh, Tomi (F/V Savage), Parker, Matt (University of Maryland), Pomeroy, Robert (Connecticut Sea Grant), Posada, Ben (Mississippi State University), Robidoux, Jaclyn (Maine Sea Grant), Roy, Luke (Auburn University), Sannito, Chris (Alaska Sea Grant), Smith, Brennan (USDA), Talley, Teresa (California Sea Grant), Vadopalas, Brent (University of Washington), Van Senten, Jonathan (Virginia Tech University), Valderrama, Diego (George Mason University), Warner, Tammy (Keene State University)

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Education

M.S. Marine Biology. 2010. University of Alaska Fairbanks. Thesis: Susceptibility of microscopic life stages to sedimentation and light attenuation in canopy-forming kelp species in Alaska.

B.S. (Honors) Natural Resource Management. 2008. University of Alaska Fairbanks. Thesis: Ecological changes of the marine community in Kachemak Bay, Alaska since 1976.

Professional Appointments

Oct 2014 – Current. ***Research Associate Professor.*** *Oct. 2014 – current. Alaska Sea Grant Marine Advisory Program Agent. College of Fisheries and Ocean Science, University of Alaska Fairbanks, AK, USA.*

Fishery Biologist. April 2011 – Sept. 2014 Assistant Area Management Biologist for the Bering Sea and Aleutian Islands. Alaska Department of Fish and Game. Unalaska, AK.

Relevant Experience

Actively working as the Alaska Sea Grant Mariculture Specialist with communities, industry, Alaska Native Tribes, seafood processors, community leaders, and regulators to promote marine aquaculture in Alaska. Recent efforts have involved a "farm-table" project to connect Alaska consumers to locally-grown oysters and seaweed products grown by Alaskan farmers and developing educational materials geared towards consumers, conducting a market assessment to identify technology and equipment used globally in primary processing and manufacturing of large volumes of seaweed, establishing a National Sea Grant Seaweed Hub, and establishing a pilot seaweed farm in western Alaska.

Recent Presentations and Workshops

Alaska Fisheries Development Foundation. 2021. *Seaweed Farm Start-Up Training*. Co-Host. Virtual. February, 2021.

Good, M. 2021. Steering Committee member and lead for student judging organization for Alaska Marine Science Symposium. Anchorage, AK. January 2021, 2020, 2019, 2018, 2017.

Good, M. 2021. *National Seaweed Hub Update. Alaska Sea Grant Shellfish and Seaweed Growers Project: Launching the Oyster and Seaweed Farm-to-Table Movement in Alaska*. Alaska Shellfish Growers Association Annual Meeting. Virtual. January, 2021.

Good, M. 2020. *Alaska Sea Grant Shellfish and Seaweed Growers Project: Launching the Oyster and Seaweed Farm-to-Table Movement in Alaska*. Pacific Coast Shellfish Growers Association Annual Shellfish Conference and Tradeshow. Virtual. October, 2020.

Good, M. 2020. *Alaska Sea Grant Shellfish and Seaweed Growers Project: Launching the Oyster and Seaweed Farm-to-Table Movement in Alaska*. Alaska Food Policy Council. Virtual. November, 2020.

Concepcion, A., Bradt, G., Chadsey, M., Chambers, M., Clemetson, A., Good, M., Otts, S., Reitsma, J., Kotowicz, D., Robidoux, J. 2020. *Seaweed Symposium*. National Sea Grant funded project. Providence, RI. March, 2020.

Alaska Fisheries Development Foundation. 2020. *Seaweed Farm Start-Up Training*. Co-Host. Kodiak, AK. February, 2020.

Good, M. 2020. *The Perfect Storm: Establishing a Pilot Seaweed Pilot Farm on the Alaska Peninsula and a National Seaweed Hub*. Alaska Shellfish Growers Association Annual Meeting. Ketchikan, AK. January, 2020.

COASST, Good, M. 2020. *Unabated Mass Mortality of Marine Birds in the Northeast Pacific*. Alaska Marine Science Symposium. Poster. 2020

Ashton, G., McCann, L., O'Mahoney, M., Good, M., Shaw, L. *Dutch Harbor Marine Invasive Species Bioblitz.* NOAA Award No. NA18NMF4370235. Unalaska, AK. March, 2020.

Good, M. Divine, L., Poe, A. *Creating a Citizen Science Monitoring Program to Detect Species Range Shifts in the Bering Sea*. Species on the Move, Skukuza, South Africa. July 2019.

Good, M. 2019. Opening introduction for Lowell Wakefield Fisheries Symposium. Anchorage, AK. May 2019.

Good, M. 2019. Lowell Wakefield Fisheries Symposium session chair on Industry and Community Engagement. Anchorage, AK. May 2019.

Ashton, G., McCann, L., Good, M., and Shaw, L. *Marine Invasive Species Bioblitz*. Poster presented at the Alaska Invasive Species Workshop and Conference. Homer, AK. Nov. 2018.

Recently Funded Projects

- NOAA Sea Grant Addressing Economic and Market Needs of the US Aquaculture Industry: *Business and Economic Planning for Seaweed Aquaculture Systems in the United States.* $129,674 PI Fong
- NOAA Sea Grant Advanced Aquaculture Collaborative Programs. 2019-2022. *Nurturing the Successful Growth and Maturation of a Domestic Seaweed Aquaculture Industry: Identifying and Removing Barriers and Promoting Opportunities*. $1,085,131. Co-PI Melissa Good.
- NOAA Sea Grant Exploring New Aquaculture Opportunities. 2019-2021*. The Perfect Storm: Establishing a Pilot Seaweed Farm in the Alaska Peninsula*. $99,751. PI Melissa Good.
- Denali Commission: *Market Assessment for Manufacturing and Sales of Alaska Seaweed.* Subaward. $55,000 PI Melissa Good

Collaborators

Aaron Poe Alaska Conservation Foundation, Anoushka Concepcion Connecticut Sea Grant, Antionette Clemetson New York Sea Grant, Arkady Savinetsky Russian Academy of Sciences, Brenda Konar University of Alaska Fairbanks, Charlotte Levy Aleutians East Borough, Dawn Kotowicz Rhode Island Sea Grant, Dixie West University of Kansas, Gabriela Bradt New Hampshire Sea Grant, Gail Ashton Smithsonian Institute, Gay Sheffield Alaska Sea Grant, Jaclyn Robidoux Maine Sea Grant, Jared Weems University of Alaska Fairbanks, Josh Reitsma Cape Cod Cooperative Extension, Lauren Divine Aleut Community of St Paul Island Tribal, Government, Linda McCann, Linda Shaw Smithsonian Institute, Matthew Edwards San Diego State University, Meg Chadsey Washington Sea Grant, Michael Chambers University of New Hampshire, Michael Etnier University of Washington, Quentin Fong Alaska Sea Grant, Robert Pomeroy Connecticut Sea Grant, Stephanie Otts National Sea Grant Law Center, Tammy Warner Keene State College, Veronica Padula Aleut Community of St Paul Island Tribal Government, Virginia Hatfield Museum of the Aleutians

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SELECT PROFESSIONAL EXPERIENCE

Prince William Sound Science Center; President and CEO and
Oil Spill Recovery Institute; Executive Director (November 2011-present)
Manage research, education, development, communications, and administration staff dedicated to advancing community resilience and the understanding and sustainable use of ecosystems. Administrative PI of EVOSTC-funded Gulf Watch Alaska (2012-present) and the ADF&G-funded Interactions of Hatchery and Wild Pink and Chum Salmon ('12-'20). Facilitate collaborations to improve the quality of research, education, and community benefit programs in the bioregion. Direct funds to improve oil spill response and recovery and knowledge of Arctic and sub-Arctic ecosystems where oil spills may occur.

Washington Sea Grant, Coastal Resources Specialist (2007-2011)
Secured $777K federal grant to coordinate an international sustainable shoreline development initiative. Chaired Sustainable Coastal Communities Action Team for West Coast Governors' Alliance on Ocean Health; led creation of tri-state work plan focused on economic development, sustainable aquaculture, sustainable fisheries, non-consumptive tourism and recreation, green ports, and clean marinas. Created quarterly science-based trainings for ~350-member Shoreline and Coastal Planners Group. Co-developed nationally recognized climate adaptation training with the NERR Coastal Training Program. Coordinated Washington State Geoduck Aquaculture Research Program conference.

NEPTUNE Project, **Grant Writer and Research Assistant, University of Washington** (**2006-2007)**
Wrote education component of the largest federal grant ever awarded to UW at the time ($126 million from NSF) to build and administer a seafloor cabled observatory, the regional cabled array of the Ocean Observatory Initiative (formerly known as NEPTUNE). Graduate thesis assessing the education potential of observatory-related engineering software.

University of Washington, Instructor and Teaching Assistant (2006)
Managed 25 visiting scholars for semester-long graduate seminar at UW School of Marine and Environmental Affairs; co-designed syllabus, maintained course web site, grades and communications. Lead instructor for marine resources unit in Program on the Environment summer course. Developed and taught lecture materials and fieldwork to students from Japan and China in a summer intensive sustainable development institute.

Occidental College, Grant Administrator, Program Coordinator, Resource Teacher (2003-2005)
Lead instructor and administrator of $990,000 HHMI grant to train middle school and high school teachers and students about the nature of scientific research using oceanography and marine ecology. Led multi-week professional development courses for ~90 science teachers, conducted classroom site visits & master instruction; led ~180 research cruises on Santa Monica Bay. Directed students in fieldwork to generate long-term, web-based data sets; guided research projects based on student-gathered data. Regularly used: CTD; secchi disk; trawl nets; Van Veen grab; nutrient analysis; video microscopy.

Mira Costa High School, Science Teacher (2001-2003)
Instructor of Marine Science and College Preparatory Biology to 9th-12th graders. Quadrupled enrollment in marine science course and served as sole curriculum developer. Developed and coordinated annual 8-month long field-based marine ecology research projects. Arranged student service-learning experiences at numerous marine facilities. Raised over $18,000 to facilitate four multi-day tall ship-based oceanographic field trips. Directed $10,000 grant for purchase of classroom aquarium system.

Monterey Bay Aquarium Research Institute, Assistant Researcher (2000)
Conducted biological and chemical oceanography research aboard a NOAA Tropical Atmosphere Ocean monitoring cruise in the Equatorial Pacific. Collected data to: monitor plankton productivity; determine the effect of phenomena such as El Nino on biological processes; measure oxygen isotopes; measure dissolved organic nutrients. Research methods include 14C incubations, nutrient and chlorophyll analysis.

University of California Berkeley, Research Technician (1997-1998)
Conducted algae genomics and protein biochemistry research using cell and molecular techniques (e.g. gel electrophoresis, DNA sequencing; recombinant DNA; algal culture maintenance and harvesting) to determine the structure and function of uncharacterized proteins in the photosynthetic pathway.

RECENT PUBLICATIONS & COLLABORATORS

Lindeberg, M., and **K. Hoffman**. 2020. Program Management I – Program coordination and science synthesis and Program Management II – Administration, science review panel, PI meeting logistics, outreach, and community involvement. *Exxon Valdez* Oil Spill Long-Term Monitoring Program (Gulf Watch Alaska) Annual Report (*Exxon Valdez* Oil Spill Trustee Council Project: 19120114-A and B), *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

Lindeberg, M., and **K. Hoffman**. 2019. Program Management I – Program coordination and science synthesis and Program Management II – Administration, science review panel, PI meeting logistics, outreach, and community involvement. *Exxon Valdez* Oil Spill Long-Term Monitoring Program (Gulf Watch Alaska) Annual Report (Restoration Project: 18120114-A and B), *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

Lindeberg, M., and **K. Hoffman**. 2018. Program management I—Program coordination and science synthesis and program management II—Administration, science review panel, PI meeting logistics, outreach, and community involvement. FY17 annual report to the *Exxon Valdez* Oil Spill Trustee Council, projects 17120114-A and B.

Hoffman, K., and M. McCammon. 2017. Program coordination, logistics, and outreach. *Exxon Valdez* Oil Spill Trustee Council Restoration Project Final Report (Restoration Project: 16120114-B), Prince William Sound Science Center, Cordova, Alaska.

Collaborators: Aderhold, Donna (PWSSC); Arimitsu, Mayumi (USGS); Bochenek, Rob, (Axiom); Buckelew, Stacey (Axiom); Coletti, Heather (NPS); Danielson, Seth (UAF); Esler, Dan (USGS); Gorman, Kristen (UAF); Holderied, Kris (NOAA); Hopcroft, Russ (UAF); Josephson, Ron (ret. ADF&G); Knudsen, Eric; Lindeberg, Mandy (NOAA), McCammon, Molly (AOOS); Morse, Kate (CRWP); Morton, Kes (OTN-Dalhousie); Rand, Pete (PWSSC); Riemer, Tara (ASLC); Suryan, Rob (NOAA); Walker, Seth (curate.org); Wisdom, Sheyna (AOOS)

EDUCATION

University of Washington, School of Marine and Environmental Affairs; M.M.A. (2007)
Chapman University: California Clear Teaching Credential, Biological Sciences (2004)
Oberlin College: B.A. Biology and B.A. Environmental Studies (1997)

Jordan A. Hollarsmith

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center
17109 Pt. Lena Loop Road. Juneau, AK, 99801
Email: Jordan.hollarsmith@noaa.gov
Work from home contact: (415) 527-6484

EDUCATION

Ph.D. Ecology, 2014-2019 **University of California, Davis**
Thesis: Foundation species across environmental gradients: refugia, adaptation, and undiscovered populations
Advisor: Edwin D. Grosholz

B.A. Ecology, Evolution and Environmental Biology **Columbia University, New York**
2008-2012
Thesis: Success of outplanted *Acropora cervicornis* colonies in reef restoration
Advisor: Sean Griffin (NOAA NMFS)

PROFESSIONAL APPOINTMENTS

Mariculture and Macroalgae Lead Research Biologist
10/2020 – present **NMFS Alaska Fisheries Science Center**
Research focus: macroalgae and mariculture in Alaska, including ecological impacts of mariculture, mariculture best practices, and macroalgae ecology.

Canadian Healthy Oceans Network Postdoctoral Fellow
07/2019 – 09/2020 **Simon Fraser University, Fisheries and Oceans Canada**
Research focus: strategies for sustainable marine resource management given cumulative and non-linear effects, with a case study using semi-quantitative models to collaboratively assess multiple stressor impacts on Salish Sea kelp ecosystems.
Collaborators: Drs. Isabelle Côté and Thomas Therriault

SELECT PUBLICATIONS

Velasco-Lozano, M. F., G. Ramírez-Ortiz, H. Reyes-Bonilla, **J. A. Hollarsmith**. (In press). Ensamblajes de peces en ecosistemas mesofóticos insulares del Pacífico mexicano. *Ciencias Marinas*.

Hollarsmith, J. A., G. Ramírez-Ortiz, T. Winquist, M. Velasco-Lozano, K. DuBois, H. Reyes-Bonilla, K. C. Neumann, E. D. Grosholz. (2020). Habitats and fish communities at mesophotic depths in the Mexican Pacific. *Journal of Biogeography.* https://doi.org/10.1111/jbi.13842

Hollarsmith, J. A., C. Camus, A. Buschmann, E. D. Grosholz. (2020) Varying reproductive success under ocean warming and acidification across giant kelp (*Macrocystis pyrifera*) populations. *Journal of Experimental Marine Biology and Ecology, 522,* 151247. https://doi.org/10.1016/j.jembe.2019.151247

Bashevkin, S., C. Dibble, R. Dunn, **J. A. Hollarsmith**, G. Ng, E. Satterthwaite, S. Morgan. (2020). Larval dispersal in a changing ocean with an emphasis on upwelling regions. *Ecosphere*, *11*(1), e03015. https://doi.org/10.1002/ecs2.3015

Hollarsmith, J. A., J. Sadowski, M. Picard, B. Cheng, J. Farlin, A. Russell, E. D. Grosholz. 2019. Effects of seasonal upwelling and runoff on water chemistry and growth and survival of native and commercial oysters. *Limnology and Oceanography*, lno.11293. https://doi.org/10.1002/lno.11293

Williams, S. L., C. Sur, N. Janetski, **J. A. Hollarsmith**, S. Rapi, L. Barron, L., S. J. Heatwole, A. M. Yusuf, S. Yusuf, J. Jompa, F. Mars. 2019. Large-scale coral reef rehabilitation after blast fishing in Indonesia. *Restoration Ecology*, 27(2), 447–456. https://doi.org/10.1111/rec.12866

SELECT FUNDING & AWARDS

2019	The University of California Institute for Mexico and the United States (UC MEXUS) and Mexico's National Council for Science and Technology (CONACYT) Postdoctoral Fellowship (declined)
2018	University of California Institute for Mexico and the United States (UC MEXUS) Small Grants Program ($1,500).
2017	National Science Foundation Graduate Research Internship Program (NSF GRIP) in collaboration with the NOAA National Marine Fisheries Service, Seattle, WA ($5,000).
2017	National Geographic Society Committee for Research and Exploration, grant number CP-095ER-17 ($5,189).
2016	National Science Foundation Graduate Research Opportunities Worldwide (NSF GROW) and Chile's National Commission for Scientific and Technological Research (CONICYT) ($10,000).
2014	National Science Foundation Graduate Research Fellowship Program (NSF GRFP)

COLLABORATORS

Andrews, Kelly S. (National Marine Fisheries Service [NMFS]), Bashevkin, Samuel M. (Delta Stewardship Council), Bishop, Alicia (NMFS), Buckner, Emily (Washington Sea Grant), Buschmann, Alejandro (Universidad de los Lagos), Calloway, Max (Washington Department of Natural Resources), Camus, Carolina (Universidad de los Lagos), Cheng, Brian (University of Massachusetts), Cote, Isabelle (Simon Fraser University [SFU]), Dibble, Connor (Scoot Science), DuBois, Katherine (Bowdoin College), Grosholz, Edwin (University of California-Davis [UCD]), Heatwole, Siobahn J. (UCD), Janetski, Noel (Mars, Inc.), Jompa, Jamaluddin (Universitas Hassanudin [UNHAS]), Mars, Frank (Mars, Inc.), Morgan, Steven G. (UCD), Naar, Nicole (Washington Sea Grant), Neumann, Kyle C. (University of California-Santa Barbara [UCSB]), Ng, Gabriel (Smithsonian Environmental Research Center), Obaza, Adam (Paua Marine), Picard, Manon M. M. (SFU), Pinchuk, Alexei (University of Alaska-Fairbanks [UAF]), Ramírez-Ortiz, Georgina (Centro de Investigacion Biologica del Noroeste), Rapi, Saipul (UNHAS), Reyes-Bonilla, Hector (Universidad Autonoma de Baja California Sur [UABCS]), Russell, Ann (UCD), Sadowski, Jason S. (Pathr.ai), Satterthwaite, Erin V. (UCSB), Scheer, Markos (Seagrove Kelp Co.), Selleck, James (NMFS), Starko, Samuel (University of Victoria), Stephens, Tiffany (Seagrove Kelp Co.), Therriault, Thomas (Fisheries and Oceans Canada), Tonnes, Dan (NMFS), Umanzor, Schery (UAF), Velasco-Lozano, Manuel (UABCS), Vollenweider, Johanna (NMFS), Williams, Susan L. (UCD), Winquist, Tallulah (UCD)

Dr. Amanda L. Kelley
University of Alaska Fairbanks
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Cell Phone: 503-407-0968, Email: alkelley@alaska.edu

EDUCATION

2013 - 2016 **Postdoctoral Research Fellow**
University of California, Santa Barbara (UCSB)
Department of Ecology, Evolution and Marine Biology
Mentor: Dr. Gretchen Hofmann

2008 - 2013 **Ph.D. Ecological Physiology**
Portland State University
Department of Biology
Advisor: Dr. Catherine de Rivera

2007 **Post-baccalaureate Research Internship**
University of Washington
Friday Harbor Marine Laboratory

2005 - 2007 **B. S. Organismal Biology, *cum laude***
Portland State University
Department of Biology

RECENT POSITIONS

2020 – present Affiliate Investigator, NSF Beaufort Lagoon Ecosystem LTER
2016 – present Tenure-track Assistant Professor, University of Alaska Fairbanks
2016 – 2018 co-Director, Ocean Acidification Research Center, UAF

RECENT GRANTS AND FUNDING

2021 – 2023 INBRE/NIH, Investigating the physiological impacts of climate stressors on Pink Salmon. Sole PI. ($259,852)
2020 – 2022 Alaska Sea Grant, Geographic variation of nearshore carbonate chemistry in the Gulf of Alaska. Sole PI. ($10,000 research funds and two years of graduate student funding)
2019 – 2021 National Oceanic and Atmospheric Administration, Thresholds in a changing ocean environment: bioeconomic implications to inform adaptation decisions for Alaska's salmon fisheries. PI, subaward ($73,813)
2018 – 2023 National Science Foundation- EPSCoR, Fire and Ice: Navigating Climate-Driven Landscape Shifts in Boreal Forest and Subarctic Coastal Ecosystems, co-Investigator, ($19,333,424)
2018 – 2019 National Science Foundation Kachemak Bay Ocean Change Lab, Facilities Improvement Grant, co-PI ($258,237)
2018 – 2020 Alaska Sea Grant, Potential for resilience: Examining the effects of ocean acidification on Alaskan bivalves ($110,285 research funds and two years of graduate student funding)
2017 – 2021 Bureau of Ocean Energy Management, High-frequency characterization of the physicochemical parameters of Cook Inlet, Alaska ($116,806)

RESEARCH

Peer-reviewed journal publications (10 included)

Miller, C. A., & **Kelley, A. L.** (2021). Seasonality and biological forcing modify the diel frequency of nearshore pH extremes in a subarctic Alaskan estuary. *Limnology and Oceanography*.

Miller, C. A., Bonsell, C., McTigue, N. D., & **Kelley, A. L.** (2021). The seasonal phases of an Arctic lagoon reveal the discontinuities of pH variability and CO_2 flux at the air–sea interface. *Biogeosciences*, 18(3), 1203-1221.

Miller, C. A., Pocock, K., Evans, W., & **Kelley, A. L.** (2018) An evaluation of the performance of Sea-Bird Scientific's SeaFET™ autonomous pH sensor: considerations for the broader oceanographic community. *Ocean Science*, 14(4), 751-768.

Kelley, A.L., Lunden, J.J. (2017) Meta-Analysis Identifies Metabolic Sensitivities to Ocean Acidification. *AIMS Environmental Science*. 4(5): 709-729.

Kapsenberg, L., **Kelley, A. L.**, Shaw, E. C., Martz, T. R., & Hofmann, G. E. (2015). Near-shore Antarctic pH variability has implications for the design of ocean acidification experiments. *Scientific Reports*, 5(1), 1-10.

Kelley, A. L., de Rivera, C. E., Grosholz, E. D., Ruiz, G. M., Yamada, S. B., & Gillespie, G. (2015). Thermogeographic variation in body size of *Carcinus maenas*, the European green crab. *Marine Biology*, 162(8), 1625-1635.

Jones, B., **Kelley, A. L.,** & Mincks, S. (2021). "Changes to benthic community structure may impact organic matter consumption on Pacific Arctic shelves." Conservation Physiology *In press*.

Kelley, A. L. (2014). The role thermal physiology plays in species invasion. *Conservation physiology*, 2(1).

Kelley, A. L., de Rivera, C. E., & Buckley, B. A. (2013). Cold tolerance of the invasive *Carcinus maenas* in the east Pacific: molecular mechanisms and implications for range expansion in a changing climate. *Biological invasions*, 15(10), 2299-2309.

Kelley, A. L., de Rivera, C. E., & Buckley, B. A. (2011). Intraspecific variation in thermotolerance and morphology of the invasive European green crab, *Carcinus maenas*, on the west coast of North America. Journal of Experimental Marine Biology and Ecology, 409(1-2), 70-78.

SERVICE

2020 – pres.	Committee member, National Science Foundation, Office of Polar Programs, Diversity Equity, and Inclusion Committee
2017 – 2020	Team lead, Ocean Acidification Information Exchange, NOAA
2017 – pres.	Science coordinator, National Ocean Science Bowl, Alaska Tsunami Bowl
2016 – pres.	Steering committee member, Alaska Ocean Acidification Network

COLLABORATORS

Cale Miller-UC Davis; Christina Bonsell-BOEM; Nathan D McTigue-U Texas; Arley Muth-UC Santa Cruz; Kenneth Dunton-U Texas; Katie Pocock-Hakai; Wiley Evans-Hakai; Katrin Iken-UAF; Claudine Hauri-UAF; Sarah Hardy-UAF; Anne Todgham- UC Davis, Gretchen

Brenda Konar

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Relevant Professional Experience

PI or Co-PI on multiple nearshore ecology projects, many of which are based in Kachemak Bay. Mentor of 24 past and 7 current MS and PhD students, many of which have worked on nearshore projects in Kachemak Bay.

Appointments:

2014 – Pres. Associate Dean, College of Fisheries and Ocean Sciences (CFOS), University of Alaska Fairbanks (UAF)
2012 – 2014 Academic Program Head, Graduate Program Marine Sciences & Limnology, UAF
2009 – Pres. Professor, CFOS, UAF
2004 – 2009 Associate Professor. CFOS, UAF
2000 – 2004 Assistant Professor, CFOS, UAF
1999 – 2000 Research Assistant Professor, CFOS, UAF

10 Relevant Research Products: (Students underlined)

Edwards M, **B Konar**, J-HKim, S Gabara, G Sullaway, TA McHugh, M Spector, and SL Small. 2020. Marine deforestation leads to widespread loss of ecosystem function. PLoS ONE 15:e0226173

Ulaski BP, **B Konar**, and EO Otis. 2020. Seaweed reproduction and harvest rebound in southcentral Alaska: implications for wild stock management. In Press in Estuaries and Coasts 43: 2046-2062.

Konar B, TJ Mitchell, K Iken, H Coletti, T Dean, D Esler, M Lindeberg, B Pister, and B Weitzman. 2019. Wasting disease and static environmental variables drive sea star assemblages in the northern Gulf of Alaska. Journal of Experimental Marine Biology and Ecology 520.

Metzger JR, **B Konar**, and MS Edwards. 2019. Assessing a macroalgal foundation species: community variation with shifting algal assemblages. Marine Biology 166:156.

Lind AC and **B Konar**. 2017. Effects of abiotic stressors on kelp early life-history stages. Algae 32:223-233.

Traiger SB and **B Konar**. 2017. Supply and survival: glacial melt imposes limitations at the kelp microscopic life stage. Botanica Marina 60:603-617.

Konar B, K Iken, D Monson, and B Weitzman. 2016. Influence of static habitat attributes on local and regional rocky intertidal community structure. Estuaries and Coasts 39:1735-1745.

Traiger SB, B Konar, A Doroff, and L McCaslin. 2016. Sea otters versus sea stars as major clam predators: evidence from foraging pits and shell litter. Marine Ecology Progress Series 560:73-86.

Stewart N, **B Konar**, and A Doroff. 2014. Sea otter (*Enhydra lutris*) foraging habitat use in a heterogeneous environment in Kachemak Bay off Alaska. Bulletin of Marine Science 90: 921-939.

Konar B, K Iken, M Edwards. 2009. Depth-stratified community zonation patterns on Gulf of Alaska rocky shores. Marine Ecology 30:63-73

5 Other Significant Publications (Students underlined)**:**

Rasher DB, RS Steneck, J Halfar, KJ Kroeker, JB Ries, MT Tinker, PT Chan, J Fietzke, NA Kamenos, **BH Konar**, and JS Lefcheck. 2020. Keystone predators govern the pathway and pace of climate impacts in a subarctic marine ecosystem. Science 369:1351-1354.

Edwards MS and **B Konar**. 2020. Trophic downgrading reduces spatial variability on rocky reefs. Scientific Reports 10:1-12.

Gabara SS, BP Weitzman, BH Konar, and MS Edwards. 2020. Macroalgal defense phenotype correlates with herbivore abundance. Marine Biology, 167:1-12.

Gabara SS, BP Weitzman, BH Konar, and MS Edwards. 2020. Macroalgal defense phenotype correlates with herbivore abundance. Marine Biology 167:1-12,

Krumhansl KA, DK Okamoto, A Rassweiler, M Novak, JJ Bolton, KC Cavanaugh, SD Connell, CR Johnson, **B Konar,** et al. 2016. Global patterns of kelp forest change over the past half-century. PNAS 29:13785-13790.

Education:

San Jose State University, San Jose, CA	Zoology	B.A. 1986
Moss Landing Marine Laboratories, CA	Marine Sciences	M.S. 1991
University of California, Santa Cruz	Biology	Ph.D. 1998

Collaborations:

Ballachey, Brenda (USGS), Benedetti-Cecci, Lisandro (University of Pisa, Italy), Bodkin, James (USGS), Byrnes, Jarrett (University of Massachusetts, Boston), Carr, Mark (University of California, Santa Cruz), Coletti, Heather (NPS), Connell, Sean (The University of Adelaide), Dunton, Ken (University of Texas), Edwards, Matt (San Diego State University), Esler, Dan (USGS), Estes, James (University of California, Santa Cruz), Holderied, Kris (NOAA), Iken, Katrin (UAF), Johnson, Craig (University of Tasmania, Hobert, Australia), Kelley, Amanda (UAF), Kenner, Michael (University of California, Santa Cruz), Krumhansl, Kira (Simon Fraser University), Lindeberg, Mandy (NOAA), Ling, Scott (University of Tasmania, Hobert, Australia), McTeague, Nathan (University of Texas), Micheli, Fiorenza (Stanford University), Miloslavich, Patricia (Simon Bolivar University, Venezuela), Monson, Dan (USGS), Munk LeeAnn (University of Alaska Anchorage), Norderhaug, Kjell (Norwegian Institute for Water Research), Perez-Matus, Alejandro (Universidad de Los Lagos, Chile), Rasher, Doug (Bigelow Laboratory), Reed, Dan (University of California, Santa Barbara), Saupe, Sue (CIRCAC), Schonberg, Susan (University of Texas), Schram, Julie (University of Alaska Southeast), Steneck, Robert (University of Maine), Tinker, Tim (University of California, Santa Cruz), Umanzor, Schery (UAF), Veasey, Pips (UAF), Wernberg, Thomas (University of Western Australia, Australia)

Curriculum Vitae
William Christopher Long
NOAA, National Marine Fisheries Service

PERSONAL INFORMATION

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Office Address: Kodiak Fisheries Research Center, 301 Research Court, Kodiak, AK 99615
Office Phone: 907-481-1715, Cell Phone: 907-654-9176, Email: chris.long@noaa.gov

EDUCATION

Ph.D. Marine Science:	Virginia Institute of Marine Science, The College of William and Mary. Jan., 2008
B.S. Biology:	Wheaton College, IL, Dec. 2000.

RECENT POSITIONS

2009-Current: **Research Ecologist.** NOAA, National Marine Fisheries Service
2018-Current: **Graduate Faculty, Special Member.** University of Maryland Eastern Shore. Department of Natural Sciences/Living Marine Resources Cooperative Science Center
Oct. 2018-Mar. 2019: **Acting Program Manager.** Shellfish Assessment Program. NOAA. National Marine Fisheries Service.

PUBLICATIONS

Related to current proposal

Long, W.C., P.A. Cummiskey, E. Munk. 2018. How does release density affect enhancement success for hatchery-reared red king crab? Canadian Journal of Fisheries and Aquatic Sciences. 75(11):1940-1948.

Long, W.C., B. Daly. 2017. Upper thermal tolerance in red and blue king crabs: sublethal and lethal effects. Marine Biology. 164:162.

Long, W.C., S. Van Sant, J.A. Haaga. 2015. Habitat, predation, growth, and coexistence: Could interactions between juvenile red and blue king crabs limit blue king crab productivity? Journal of Experimental Marine Biology and Ecology. 464:58-67.

Ryer, C.H., W.C. Long, M.L. Spencer, P. Iseri. 2015. Depth distribution, habitat associations, and differential growth of newly settled southern Tanner crab (*Chionoecetes bairdi*) in embayments around Kodiak Island, Alaska. Fisheries Bulletin. 113:256-269.

Long, W.C., R.D. Seitz, B.J. Brylawski, R.N. Lipcius. 2014. Individual, population, and ecosystem effects of hypoxia on a dominant benthic bivalve in Chesapeake Bay. Ecological Monographs. 84:303-327.

Long, W.C., L. Whitefleet-Smith. 2013. Cannibalism in red king crab: Habitat, ontogeny, and the predator functional response. Journal of Experimental Marine Biology and Ecology. 449:142-148.

Long, W.C., A. Sellers, A.H. Hines. 2013. Mechanism by which coarse woody debris affects predation and community structure in Chesapeake Bay. Journal of Experimental Marine Biology and Ecology. 446:297-305.

Long, W.C., J. Grow, J. Majoris, A.H. Hines. 2011. Effects of anthropogenic shoreline hardening and invasion by *Phragmites australis* on habitat quality for juvenile blue crabs (*Callinectes sapidus*). Journal of Experimental Marine Biology and Ecology. 409:215-222.

Long, W.C., R.D. Seitz. 2009. Hypoxia in Chesapeake Bay tributaries: Worsening effects on macrobenthic community structure in the York River. Estuaries and Coasts. 32:287-297.

Long, W.C., R.D. Seitz. 2008. Trophic interactions under stress: hypoxia enhances foraging in an estuarine food web. Marine Ecology Progress Series. 362:59-68.

Other publications

Long, W.C., P. Pruisner, K.M. Swiney, R.J. Foy. 2019. Effects of ocean acidification on respiration, feeding, and growth of juvenile red and blue king crabs (*Paralithodes camtschaticus* and *P. platypus*). ICES Journal of Marine Science. 76(5):1335-1343.

Long, W.C., S.B. Van Sant, K.M. Swiney, R.J. Foy. 2017. Survival, growth, and morphology of blue king crabs: Effect of ocean acidification decreases with exposure time. ICES Journal of Marine Science. 74(4):1033-1041.

Swiney K.M., W.C. Long, R.J. Foy. 2016. Effects of ocean acidification on Tanner crab reproduction and early life history, Part I: long-term exposure reduces hatching success and female calcification, and alters embryonic development. ICES Journal of Marine Science. 73(3):825–835.

Long, W.C., K.M. Swiney, R.J. Foy. 2016. Effects of ocean acidification on Tanner crab reproduction and early life history, Part II: carryover effects on larvae from oogenesis and embryogenesis are stronger than direct effects. ICES Journal of Marine Science. 73(3):836–848.

Long, W.C. 2016. A new quantitative model of multiple transitions between discrete stages, applied to the development of crustacean larvae. Fisheries Bulletin. 114:58-66.

Collaborations in the last 4 years

David Armstrong (University of Washington), Jan Armstrong (University of Washington), Richard Aronson (Florida Institute of Technology), Kerstin Baran (College of New Jersey), Shai Bejerano (College of New Jersey), Peter Cummiskey (Alaska Fisheries Science Center), Gary Dickinson (College of New Jersey), Lauren Divine (Aleut Community of St. Paul), Ginny Eckert (University of Alaska), Robert Foy (Alaska Fisheries Science Center), Jennifer Gardner (Alaska Fisheries Science Center), Kirstin Holsman (Alaska Fisheries Science Center), Thomas Hurst (Alaska Fisheries Science Center), Sean McDonald (University of Washington), Christine Makdisi (College of New Jersey), Stephanie Martínez-Rivera (University of Maryland Eastern Shore), Erik Munk (Alaska Fisheries Science Center), Krista Nichols (Northwest Fisheries Science Center), Shrey Patel (College of New Jersey), Paige Puisner (University of Colorado), Jonathan Reum (Alaska Fisheries Science Center), Jon Richar (Alaska Fisheries Science Center), Miranda Rosen (College of New Jersey), Trina Salvador (College of New Jersey), Justin Sison (College of New Jersey), Kathryn Smith (The Marine Biological Association), Ingrid Spies (Alaska Fisheries Science Center), Brittan Steffel (Florida Institute of Technology), Bradley Stevens (University of Maryland Eastern Shore), Katherine Swiney (Southwest Fisheries Science Center), Jared Weems (University of Alaska), Leah Zacher (Alaska Fisheries Science Center).

Alexei I. Pinchuk

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PROFESSIONAL PREPARATION:

St. Petersburg State University	**Biology/Hydrobiology**	**B.Sci./M.Sci. 1987**
University of Alaska Fairbanks	**Biological Oceanography**	**M.Sci. 1997**
University of Alaska Fairbanks	**Oceanography**	**Ph.D. 2006**

APPOINTMENTS:

Research Associate Professor: College of Fisheries and Ocean Sciences, Fisheries Division, University of Alaska Fairbanks, 2015-current

Research Assistant Professor: School of Fisheries and Ocean Sciences, Fisheries Division, University of Alaska Fairbanks, 2011-2015

Postdoctoral Research Professional 5, ACT (Alliance for Coastal Technologies) Technical Coordinator: Seward Marine Center, University of Alaska Fairbanks, 2006-2010

Research Assistant, Research Technician, Research Associate, Research Professional 2: Institute of Marine Science, University of Alaska Fairbanks, 1994-2006

TEN MOST RECENT/RELEVANT PUBLICATIONS:

Pinchuk A.I., Batten S.D., Strasburger W.W. 2021. Doliolid (Tunicata, Thaliacea) blooms in the southeastern Gulf of Alaska as a result of the recent marine heat wave of 2014-2016. *Frontiers in Marine Science,* 8: 625486.

Tempestini A., **Pinchuk A.I.**, Dufresne F. 2020. Spatial structuring in a cryptic amphipod *Themisto libellula* from the coastal Gulf of Alaska, Bering and Chukchi seas. *Polar Biology* 43(11): 1795-1804.

Pinchuk A.I., Eisner L.B. 2017. Spatial heterogeneity in zooplankton summer distribution in the eastern Chukchi Sea in 2012–2013 as a result of large-scale interactions of water masses. *Deep Sea Research II* 135: 27-39.

Tamburri M.N., Johengen T.H., Atkinson M.J., Schar D.W.H., Robertson C.Y., Purcell H., Smith G.J., **Pinchuk A.I.,** Buckley E.N. 2011. Alliance for Coastal Technologies: advancing moored pCO_2 instruments in coastal waters. *Marine Technology Society Journal* 45(1): 43-51.

Pinchuk A.I., Coyle K.O., Hopcroft R.R. 2008. Climate-related changes in abundance and reproduction of dominant euphausiids in the northern Gulf of Alaska in 1998-2003. *Progress in Oceanography* 77: 203-216.

Pinchuk A.I., Hopcroft R.R. 2007. Seasonal variations in the growth rates of euphausiids (*Thysanoessa inermis*, *T. spinifera*, and *Euphausia pacifica*) from the northern Gulf of Alaska. *Marine Biology* **151**: 257-269.

Adams C.F., **Pinchuk A.I.,** Coyle K.O. 2007. Seasonal changes in the diet composition and prey selection of walleye pollock (*Theragra chalcogramma*) in the northern Gulf of Alaska. *Fisheries Research* 84: 378-389

Pinchuk A.I., Hopcroft R.R. 2006. Egg production and early development of *Thysanoessa inermis* and *Euphausia pacifica* (Crustacea: Euphausiacea) in the northern Gulf of Alaska. *Journal of Experimental Marine Biology and Ecology* 332: 206-215.

Coyle K.O., **Pinchuk A.I.** 2005. Seasonal cross-shelf distribution of major zooplankton taxa on the northern Gulf of Alaska shelf relative to water mass properties, species depth preferences and vertical migration behavior. *Deep-Sea Research II* 52: 217-245.

Coyle K.O., **Pinchuk A.I.** 2003. Annual cycle of zooplankton abundance, biomass and production on the northern Gulf of Alaska shelf, October 1997 through October 2000. *Fisheries Oceanography* 12(4/5): 327-338.

FIVE OTHER SIGNIFICANT PUBLICATIONS:

Eisner L.B., **Pinchuk A.I**., Kimmel D.G., Mier K.L., Harpold C., Siddon E.C. 2018. Seasonal, interannual, and spatial patterns of community composition over the eastern Bering Sea shelf in cold years. Part I: zooplankton. *ICES Journal of Marine Science* 75(1): 72-86*.*

Sigler M.F., Mueter F.J., Bluhm B.A., Busby M.S., Cokelet E.D., Danielson S.L., De Robertis A., Eisner L.B., Farley E.V., Iken K., Kuletz K.J., Lauth R.R., Logerwell E.A., **Pinchuk A.I.** 2017. Summer zoogeography of the northern Bering and Chukchi seas. *Deep Sea Research II* 135: 168-189.

Pinchuk A.I., Harvey H.R., Eckert G.L. 2016. Development of biochemical measures of age in the Alaskan red king crab (*Paralithodes camtschaticus*): validation, refinement and initial assessment. *Fisheries Research* 183: 92-98.

Pinchuk A.I., Coyle K.O., Farley E.V., Renner H.R. 2013. Emergence of the Arctic *Themisto libellula* (Amphipoda: Hyperiidae) on the southeastern Bering Sea shelf as a result of the recent cooling, and its potential impact on the pelagic food web. *ICES Journal of Marine Science* **70**: 1244-1254

Coyle K.O., Eisner L.B., Mueter F.J., **Pinchuk A.I.,** Janout M.A, Farley E.V., Cieciel K., Andrews A.G. 2011. Climate change in the southeastern Bering Sea impacts on pollock stocks and implications for the Oscillating Control Hypothesis. *Fisheries Oceanography* 20(2): 139-156

SYNERGISTIC ACTIVITIES:

Member of an NSF Proposal Review Panel (2016)

Referee: manuscripts for Polar Biology, Marine Biology, Marine Ecology Progress Series, Progress in Oceanography, Deep-Sea Research Parts I and II, ICES Journal of Marine Science, Limnology & Oceanography, Journal of Marine Systems, Aquatic Biology, Journal of Biogeography, Continental Shelf Research, Frontiers in Marine Science, Journal of Experimental Marine Biology and Ecology, Journal of Plankton Research, proposals for NSF, NPRB, NOAA (FATE), PCCRC.

CURRENT AND RECENT PROJECTS:

2019-2024: Cooperative Training and Research for Alaska Fisheries Science*, Lead PI, funded by NOAA*

2019-2023: RII Track-1: Fire and Ice: Navigating Variability in Boreal Wildfire Regimes and Subarctic Coastal Ecosystems. *PI, funded by NSF EPSCOR.*

2019-2021: Utilization of the under-ice habitat by Arctic Cod in the western Arctic Ocean: a multidisciplinary collaborative study*, PI (with F. Mueter), funded by BOEM -Coastal Marine Institute*

2019: Biological Productivity in Arctic Lagoons: Diversity, Seasonal Development and Interannual Dynamics of Zooplankton Populations, *Lead PI, funded by Wildlife Conservation Society.*

2018-2019*:* Trophic Interactions in Subarctic Pelagic Ecosystems: Fish, Medusae and Zooplankton. *Lead PI, funded by Alaska SeaGrant Omnibus.*

2016-2018: Feeding habits of juvenile salmon, forage fish and scyphozoan jellyfish in the northern Bering Sea and Gulf of Alaska. *Lead PI, funded by CIFAR-NOAA.*

2014-2018: Ecology of forage fish in the Beaufort and Chukchi Seas. *PI (with R. Heintz, B. Norcross and others), funded by BOEM.*

RECENT COLLABORATORS:

S.D. Batten (PICES), K. Boswell (International University of Florida), L. Copeman (OSU-NOAA), S.L. Danielson (UAF), F. Dufresne (U. du Québec à Rimouski), L.B. Eisner (NOAA), E. Farley (NOAA), H. Flores (Alfred Wegener Institute), G. Gibson (UAF), R. Heintz (NOAA), G.L. Hunt, Jr. (UW), B. Konar (UAF), K.J. Kuletz (FWS), E. Lessard (UW), C. Li (Louisiana State University), F. Mueter (UAF), B. Norcross (UAF), M. Robards (Wildlife Conservation Society), M. Sigler (NOAA), K. Ciecil (NOAA), L. Sousa (North Slope Borrow), W. Strasburger (NOAA), A. Tempistini (U. du Québec à Rimouski), J.J. Vollenweider (NOAA)

Michael J. Rehberg
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EDUCATION

University of Alaska Anchorage, Anchorage, Alaska

Master of Science – Biological Sciences – 2005

SUNY College of Environmental Science and Forestry, Syracuse, New York

Bachelor of Science - Environmental and Forest Biology (Wildlife Concentration) – 1991

PROFESSIONAL EXPERIENCE

Wildlife Biologist IV / Program Leader, Gulf and Bering Marine Mammal Program

June 2011 – present, Alaska Department of Fish and Game
Lead and manage a research program studying a high-profile endangered species; Supervise staff of 6 permanent employees including 3 direct reports; Working with staff, write proposals for, budget and manage $1.8M annual budget; Communicate within and outside the program to determine management-driven research needs; Consult with management agencies to provide information, comment and review.

Wildlife Biologist II – August 2005 – June 2011 Alaska
Department of Fish and Game
Lead ADF&G Steller Sea Lion Program telemetry work; Chief scientist leading Steller sea lion capture and research cruises in Alaska; Deployed archival and satellite-linked diving and movement instruments onto Steller sea lions; Developed and computed behavioral metrics using SQL, various scripting languages and GIS; Tested hypotheses using SPSS, R and specialist statistical software; Proposed and co-chaired marine mammal symposium at Wildlife Society conference, Sep. 2006.

Assistant Biometrician – August 2001 – August 2005
Alaska Department of Fish and Game
Captured and deployed instruments upon Steller sea lions, edited, archived and analyzed data; Co-PI of successful grant to compile and model improved bathymetry for coastal Alaska; Proposed and co-chaired telemetry workshops at Sea Lions of the World meeting, Oct. 2004.

Wildlife Biologist I – July 1999 – August 2001
Alaska Department of Fish and Game
Captured and deployed instruments upon Steller sea lions; edited, archived and analyzed data; Worked with manufacturer to custom-modify satellite tags and identify better adhesives; Analyzed harbor seal movement and diving behavior.

Biological Science Technician – May 1997 - July 1999
USGS Alaska Biological Science Center
Assisted walrus capture and satellite radio-tagging at remote field camps on Bristol Bay, Alaska.

FUNDING

- A trans-boundary Bering Sea knowledge exchange workshop on Steller sea lions. **Rehberg, M.** July 2020 – June 2021. $25,000. Trust for Mutual Understanding, Inc.
- Cooperative trans-boundary Bering Sea Steller sea lion surveys. **Rehberg, M.** and Jemison, L. January 2021 – December 2023. $225,000. NPS Shared Beringian Heritage Program Grant.

- Habitat use of adult female Steller sea lions in the endangered western Distinct Population Segment. **Rehberg, M.** July 2018 – June 2021. $591,441. NMFS ESA Sec. 6 Grant NA18NMF4720088
- Spatial and temporal patterns in population dynamics, plasticity of the stock boundary and residual and emerging threats to Steller sea lions. Small, R., **Rehberg, M.,** Jemison, L., Keogh, M. and Hastings, K. April 2016 – June 2019. $2,336,933. NMFS Grant NA16NMF4390029.
- Assessing alternative hypotheses for the lack of recovery of Steller sea lions in western Alaska through determination of diet composition and contaminant exposure. Rea, L. and **Rehberg, M.** July 2013 – June 2016. $1,410,825. NMFS ESA Sec. 6 Grant NA13NMF4720041
- Investigations of marine mammals in Alaska: Subproject 1, Recovery investigations of Steller sea lions in Alaska. Small, R. J., **Rehberg, M.,** Blundell, G. and Quakenbush, L. July 2013. $496,325 (Steller sea lion portion). NMFS Grant NA11NMF439020
- Investigations of marine mammals in Alaska: Subproject 1, Recovery investigations of Steller sea lions in Alaska. Small, R. J., **Rehberg, M.,** Blundell, G. and Quakenbush, L. July 2012. $506,161 (Steller sea lion portion). NMFS Grant NA11NMF439020
- Coastal bathymetry within the range of Steller sea lions in Alaska. Gelatt, T. and **Rehberg, M.** July 2001 – Sept. 2003. $44,101. NMFS Steller Sea Lion Research Initiative 01-SSL-065

PUBLICATIONS

Rehberg, M., L. Jemison, J. N. Womble and G. O'Corry-Crowe. 2018. Winter movements and long-term Dispersal of Steller sea lions in the Glacier Bay region of Southeast Alaska. Endang Species Res 37: 11-24. https://doi.org/10.3354/esr00909

Rehberg, M. J., L. D. Rea and C. Eischens. 2018. Overwintering Steller sea lion (Eumetopias jubatus) pup growth and behavior prior to weaning. Can J Zool 96: 97-106. https://doi.org/10.1139/cjz-2016-0296

Rehberg, M., R. Andrews, U. Swain and D. Calkins. 2009. Adult female Steller sea lion behavior during the breeding season in southeast Alaska. Mar Mamm Sci 25: 588- 604.

Sigler, M., Tollit, D., Vollenweider, J., Thedinga, J., Csepp, D., Womble, J., Wong, M., **Rehberg, M.** and Trites, A. 2009. Steller sea lion foraging response to seasonal changes in prey availability. Mar Ecol Progr Ser 388: 243–261.

Rehberg, M. J. and J. M. Burns. 2008. Differences in diving and swimming behavior of pup and juvenile Steller sea lions (Eumetopias jubatus) in Alaska. Can J Zool 86: 539-553.

Call, K. A., Fadely, B. S., Greig, A. and **M. J. Rehberg**. 2007. At-sea and on-shore cycles of juvenile Steller sea lions derived from satellite dive recorders: a comparison between declining and increasing populations. Deep Sea Res II 54: 298-310.

Rehberg, M. J. 2005. Pattern matters: Changes in the organization of swimming and diving behavior by Steller sea lion juveniles in Alaska. M.S. thesis, U. Alaska Anchorage. 90 pp.

Pitcher, K. W., **Rehberg, M. J.**, Pendleton, G. W., Raum-Suryan, K. L., Gelatt, T. S., Swain, U. G., and Sigler, M. F. 2005. Ontogeny of dive performance in pup and juvenile Steller sea lions in Alaska. Can J Zool 83(9): 1214-1231.

RECENT COLLABORATORS

Counihan, K., Alaska SeaLife Center; Fadely, B., NOAA Marine Mammal Lab; Hastings, K., ADF&G; Jemison, L., ADF&G; Keogh, M., NOAA Alaska Region; Maniscalco, J., Alaska SeaLife Center; O'Corry-Crowe, G., Harbor Branch Research Institute; Raum-Suryan, K., NOAA Alaska Region; Rea, L., UAF Water & Environmental Research Center; Savage, K., NOAA Alaska Region; Sheffield, G., UAF Sea Grant; Shero, M., Woods Hole Oceanographic Institute; Womble, J., National Park Service - Glacier Bay NP

ANNE SCHAEFER, M.S.

Avian Research Biologist, Prince William Sound Science Center

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EDUCATION

M.S. Wildlife Biology, 2014 University of Montana, Missoula, MT

B.S. Organismal Biology, 2011 South Dakota State University, Brookings, SD

B.A. Spanish, 2011 South Dakota State University, Brookings, SD

RELEVANT PROFESSIONAL EXPERIENCE

Avian Research Assistant, Prince William Sound Science Center, Cordova, Alaska. (August 2014 – present).

Seabird Crew Lead and Field Technician, Polar Oceans Research Group, Palmer LTER, West Antarctic Peninsula (Dec 2018 – Feb 2019, Nov 2019 – Feb 2020).

RELEVANT PUBLICATIONS & REPORTS

Arimitsu, M., J. Piatt, S. Hatch, R.M. Suryan, S. Batten, M.A. Bishop, R.W. Campbell, H. Coletti, D. Cushing, K. Gorman, R.R. Hopcroft, K.J. Kuletz, C. Marsteller, C. McKinstry, D. McGowan, J. Moran, R.S. Pegau, **A. Schaefer**, S. Schoen, J. Straley, and V. R. von Biela. 2021. Heatwave-induced synchrony within forage fish portfolio disrupts energy flow to top pelagic predators. *Global Change Biology*. https//doi.org/10.111/gcb.15556.

Schaefer, A., M.A. Bishop, and R. Thorne. 2020. Marine bird response to forage fish during winter in subarctic bays. *Fisheries Oceanography* 29(4) 297-308.

Schaefer, A., M.A. Bishop, and K. Jurica. 2019. Effects of egg harvest on egg laying of Glaucous-winged Gulls *Larus glaucescens*. *Marine Ornithology*. 47(2):185-189.

Schaefer, A. 2016. Winter species in Prince William Sound, Alaska, 1989-2016. Final Report to the Prince William Sound Regional Citizens' Advisory Council. Contract No. 910.16.01.

Schaefer, A., P.M. Lukacs, and M.L. Kissling. 2015. Testing factors influencing the identification rates of similar species during abundance surveys. *The Condor: Ornithological Applications* 117: 60–472.

Schaefer, A. 2015. Sensitivity of black turnstones to coastal threats. Report to the Oil Spill Recovery Institute, Cordova, AK.

Schaefer, A. 2014. Addressing the challenges of monitoring a rare and elusive seabird. MS Thesis, University of Montana, Missoula, MT.

Sergeant, C.J., S.T. Hoekman, W.F. Johnson, and **A. Schaefer**. 2014. Monitoring Kittlitz's and marbled murrelets in Glacier Bay National Park and Preserve: 2014 annual report. Natural Resource Technical Report NPS/SEAN/NRTR—2014/925. National Park Service, Fort Collins, Colorado.

Suryan, R., M. Arimitsu, H. Coletti, R. Hopcroft, M. Lindeberg, S. Barbeaux, S. Batten, W. Burt, M. A. Bishop, J. Bodkin, R. Brenner, R. Campbell, D. Cushing, S. Danielson, M. Dorn, B. Drummond, D.

Esler, T. Gelatt, D. Hanselman, S. Hatch, S. Haught, K. Holderied, K. Iken, D. Irons, A. Kettle, D. Kimmel, B. Konar, K. Kuletz, B. Laurel, J. Maniscalco, C. Matkin, C. McKinstry, D. Monson, J. Moran, D. Olsen, W. Palsson, S. Pegau, J. Piatt, L. Rogers, N. Rojek, **A. Schaefer**, I. Spies, J. Straley, S. Strom, K. Sweeney, M. Szymkowiak, B. Weitzman, E. Yasumiishi, and S. Zador. 2021. Ecosystem response persists after a prolonged marine heatwave. *Scientific Reports*. XX:XX-XX.

COLLABORATIONS

M. Arimitsu (USGS), M.A. Bishop (PWSSC), R. Campbell (PWSSC), M. Cimino (NOAA & UC-Santa Cruz), B. Fraser (PORG), K. Gorman (PWSSC & UAF), S. Hatch (Inst. Seabird Res. & Conserv.), N. Hill (Tufts Univ.), M. Kissling (USFWS now UM), P. Lukacs (UM), J. Moran (NOAA), R. Porter, J. Runstadler (Tufts Univ.), C. Sergeant (NPS now UM), J. Straley (UAS), Y. Suzuki (OSU), A. Taylor (UAA).

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NOAA NMFS Alaska Fisheries Science Center, Auke Bay Laboratories,
17109 Pt. Lena Loop Rd, Juneau, AK 99801 (907)789-6065, rob.suryan@noaa.gov

RELEVANT PROFESSIONAL EXPERIENCE

Research Interests: Long-term ecological investigations in marine environments working nationally and internationally. Primary interests include: marine ecosystem processes, food webs, foraging ecology, spatial ecology, population dynamics, human-resource interactions. Participation in long-term ecological research including Alaska Predator Ecosystem Experiment (EVOSTC), Bering Sea Integrated Ecosystem Research Program (NPRB), State of the California Current, Gulf Watch Alaska (EVOSTC)

Professional Appointments (selected)

Research Fish Biologist, Prog. Mgr.	NOAA Fisheries	2020-present
Research Ecologist	NOAA Fisheries	2018-2020
Associate Professor - Senior Research	Oregon State University	2012-2018
Assistant Professor - Senior Research	Oregon State University	2006-2012
NOAA Fisheries Oceanography Fellow	Oregon State University	2003-2006
Graduate Research Assistant	Oregon State University	2001-2006
Wildlife Biologist/Co-Prin. Invest.	U.S. Fish and Wildlife Service	1996-2001

Academic Appointments (current)

Affiliate Faculty: Wildlife Biology Program, University of Montana	2020-present
Courtesy Associate Professor: Department of Fisheries and Wildlife, Oregon State University	2018-present
Affiliate Faculty: College of Fisheries and Ocean Sciences, University of Alaska Fairbanks	2016-present

MOST RELEVANT PUBLICATIONS

Suryan, R.M. et al. 2021. Ecosystem response persists after a prolonged marine heatwave. Scientific Reports https://doi.org/10.1038/s41598-021-83818-5. **(EVOS-GWA)**

Arimitsu. M.L. et al. including **R.M. Suryan**. 2021. Heatwave-induced synchrony within forage fish portfolio disrupts energy flow to top pelagic predators. Global Change Biology DOI:10.1111/gcb.15556 **(EVOS-GWA)**

Wietzman, B. et al. including **R.M. Suryan**. 2021. Changes in rocky intertidal community structure during a marine heatwave in the northern Gulf of Alaska. Frontiers in Marine Science 8 10.3389/fmars.2021.556820 **(EVOS-GWA)**

Piatt, J.F et al. including **R.M. Suryan**. 2020. Extreme mortality and reproductive failure of common murres resulting from the northeast Pacific marine heatwave of 2014-2016. PLoS ONE 15:e0226087.

Thompson, A.R. et al. including **R.M. Suryan.** 2018. State of the California Current 2017-2018: Still not quite normal in the north and getting interesting in the south. California Cooperative Oceanic Fisheries Investigations Reports 59:1-66. **(annual contributor 2012-2018)**

Suryan, R.M., K.J. Kuletz, S.L. Parker-Stetter, P.H. Ressler, M. Renner, J.K. Horne, E.V. Farley, E.A. Labunski. 2016. Temporal shifts in seabird populations and spatial coherence with prey in the southeastern Bering Sea. Marine Ecology Progress Series 549:199-215. **(NPRB-BSIERP)**

Hazen, E.L., **R.M. Suryan**, J.A. Santora, S.J. Bograd, Y. Watanuki , R.P. Wilson. 2013. Scales and mechanisms of marine hotspot formation. Marine Ecology Progress Series 487:177-183.

Benoit-Bird, K.J., Battaile, B., S.A. Heppell, B. Hoover, D.B. Irons, N. Jones, K. Kuletz, C.A. Nordstrom, R. Paredes, **R.M. Suryan**, C.M. Waluk, A.J. Trites. 2013. Prey patch patterns predict habitat use by top marine predators with diverse foraging strategies. PLoS ONE 8(1):e53348. **(NPRB-BSIERP)**

Paredes R., A.M.A. Harding, D.B. Irons, D.D. Roby, **R.M. Suryan**, R.A. Orben, H. Renner, R. Young, A. Kitaysky. 2012. Proximity to multiple foraging habitats enhances seabirds' resilience to local food shortages. Marine Ecology Progress Series 471:253-269. **(NPRB-BSIERP)**

Suryan, R.M., D.B. Irons, E.D. Brown, P.G.R. Jodice, and D.D. Roby. 2006. Site-specific effects on productivity of an upper trophic-level marine predator: Bottom-up, top-down, and mismatch effects on reproduction in a colonial seabird. Progress in Oceanography 68:303-328. **(EVOS-APEX)**

OTHER SIGNIFICANT PUBLICATIONS

Gladics, A.J., **R.M. Suryan,** R.D. Brodeur, L.M. Segui, L.Z. Filliger. 2014. Constancy and change in marine predator diets across a shift in oceanographic conditions in the northern California Current. Marine Biology. 10.1007/s00227-013-2384-4

Suryan, R.M. and K.N. Fischer. 2010. Stable isotope analysis and satellite tracking reveal inter-specific resource partitioning of non-breeding albatrosses (*Phoebastria* spp.) off Alaska. Canadian Journal of Zoology 88:299-305

Jodice, P.G.R., D.D. Roby, K.R. Turco., **R.M. Suryan**, D.B. Irons, J.F. Piatt, M.T. Shultz, D.G. Rosenau, A.B. Kettle, J.A. Anthony. 2006. Assessing the nutritional stress hypothesis: the relative influence of diet quantity and quality on seabird productivity. Marine Ecology Progress Series 325:267-279**.**

Suryan, R.M., D.B. Irons, M. Kaufman, J. Benson, P.G.R. Jodice, D.D. Roby, and E.D. Brown. 2002. Short-term fluctuations in forage fish availability and the effect on prey selection and brood-rearing in the black-legged kittiwake (*Rissa tridactyla*). Marine Ecology Progress Series 236:273-287.

Suryan, R.M., D.B. Irons, and J. Benson. 2000. Prey switching and variable foraging strategies of black-legged kittiwakes and the effect on reproductive success. Condor. 102:375-385.

EDUCATION

Humboldt State University	Wildlife Management	B.S. 1989
Moss Landing Marine Laboratories	Marine Science	M.S. 1995
Oregon State University	Wildlife Science	Ph.D. 2006

COLLABORATORS

J Adams (USGS), M.L. Arimitsu (USGS), S.J. Barbeaux (NOAA), S.D. Batten (PICES), W.J. Burt (UAF), M.A. Bishop (PWSSC), J.L. Bodkin (USGS), R.E. Brenner (ADF&G), R.W. Campbell (PWSSC), H.A. Coletti (National Park Service), D.A. Cushing (Pole Star Ecological Research), S.L. Danielson (UAF), M.W. Dorn (NOAA), B. Drummond (USFWS), D. Esler (USGS), E Farley (NOAA), T Gelatt (NOAA), D.H. Hanselman (NOAA), S.A. Hatch (Institute for Seabird Research and Conservation), S. Haught (ADF&G), E Hazen (NOAA), K. Holderied (NOAA), R.R. Hopcroft (UAF), J. Horne (U of Washington), K. Iken (UAF), R.S.A. Kaler (USFWS), D.B. Iron (USFWS), A.B. Kettle (USFWS), D.G. Kimmel (NOAA), B. Konar(UAF), K.J. Kuletz (USFWS), B.J. Laurel (NOAA), M.R. Lindeberg (NOAA), J.M. Maniscalco Alaska SeaLife Center), C. Matkin (North Gulf Oceanic Society), C.A.E. McKinstry (PWSSC), D.H. Monson (USGS), J.R. Moran (NOAA), D. Olsen (NGOS), W.A. Palsson (NOAA), J. K. S Parker-Stetter (NOAA), J. Parrish (UW), W.S. Pegau (PWSSC), J.F. Piatt (USGS), D Roby (USGS), H. M. Renner (USFWS), P. Ressler (NOAA), L.A. Rogers (NOAA), N.A. Rojek (USFWS), A. Schaefer (PWSSC), S. K. Schoen (USGS), S Shaffer (San Jose State University), I.B. Spies (NOAA), J.M. Straley (UAS), S.L. Strom (WWU), K.L. Sweeney (NOAA), W. J. Sydeman (Farallon Institute), M. Szymkowiak (NOAA), B.P. Weitzman (NOAA), E.M. Yasumiishi (NOAA), and S.G. Zador (NOAA)

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PROFESSIONAL PREPARATION

CICESE, Baja California, MX	**Marine Ecology**, Ph.D.	2014-2017
New Mexico State U. NM, USA	**Ecology and Evolutionary Biology**, M.S.	2006-2008
National U. of Costa Rica, Heredia, CRI	**Marine and Freshwater Biology**, BS	2000-2005

APPOINTMENTS

07/2020 – present: **Research Assistant Professor**, College of Fisheries and Ocean Sciences, University of Alaska Fairbanks, Alaska.

05/2018 - 06/2020: **Research Associate**, Department of Ecology and Evolutionary Biology, University of Connecticut, Connecticut.

01/2013 - 12/2014: **Research Associate**, FUNDEVI, University of Costa Rica, Costa Rica

01/2011 - 12/2013: **Research Assistant,** FUNDEVI, University of Costa Rica, Costa Rica

PUBLICATIONS (selected, 2019-2021)

Umanzor, S., Han, S., Song, H.-I., Critchley, A.T., Yarish, C. and Jang, J.K. Enhancements provided by using seaweed-derived biostimulants can be transferred through monospores on the red alga *Neopyropia yezoensis*. *Submitted to Scientific Reviews. February 2021*

Umanzor, S., Han, S., Song, H.-I., Critchley, A.T., Yarish, C. and Jang, J.K. Can the interaction of seaweed-derived biostimulants and temperature induce changes in the life cycle of *Neopyropia yezoensis*? *Submitted to Algal Research. February 2021*

Umanzor, S., Sandoval-Gil, J.M., Sanchez-Barredo, M., Ladah, L., Ramírez, M.M., and Zertuche-González, J.A (2021). Stress response and recovery of juvenile sporophytes of the giant kelp (*Macrocystis pyrifera*, laminariales, phaeophyceae) to simulated marine heatwaves and nitrate scarcity. Accepted: *Journal of Phycology*

Umanzor, S., Li, Y., Bailey, D., Augyte, S., Marty-Rivera, M., Huang, M., Jannink, J-L, Yarish, C., Lindell, S. (2021). Comparative analysis of phenotypic traits of selectively bred *Saccharina* spp. sporophytes from the Northwest Atlantic Coast. *Accepted: Journal of World Aquaculture Society.*

Umanzor, S., Li, Y. and Yarish, C. (2020). Effect of direct "seeding" binders and embryonic sporophyte sizes on the development of the sugar kelp, *Saccharina latissima*. Journal of Applied Phycology 32: 4137–4143. *doi: 10.1007/s10811-020-02277-z*

Mao, X., Augyte, S., Huang, M., Hare, M. P., Bailey, D., **Umanzor, S**., Marty-Rivera, M., Robbins, K. R., Yarish, C., Lindell, S., & Jannink, J.-L. (2020). Population genetics of sugar kelp in the Northwest Atlantic region using genome-wide markers. Frontiers in Marine Science, doi: 10.3389/fmars.2020.00694

Umanzor, S., Jang, S., Antosca, R. Critchley, A.T., Yarish, C. and Kim, J.K. (2020). Optimizing the application of selected biostimulants to enhance the growth of *Eucheumatopsis isiformis*, a carrageenophyte with commercial value, as grown in land-based nursery systems. Journal of Applied Phycology 32, 1917–1922. doi:10.1007/s10811-020-02091-7

Augyte, S., G. Wikfors, S. Pitchford, M. Marty- Rivera, **Umanzor, S.**, Yarish, C., Bailey, D. and Lindell, S. (2020). The application of flow cytometry for kelp meiospore isolation. Algal Research, 48: 101810, doi: 10.1016/j.algal.2020.101810

Umanzor, S., Shin, S. Marty-Rivera, M., Augyte, S., Yarish, C. and Kim, J.K. (2019) Exploratory evaluation of the effects of Kelpak® seaweed extract on cultivated kelp *Saccharina* spp. exposed to sublethal and lethal temperatures. Journal of World Aquaculture Society, 1-10, doi.org/10.1111/jwas.12687

Umanzor, S., Ramírez, M.M., Sandoval-Gil, J.M., Zertuche-González, J.A, and Yarish, C. (2019). Evaluation of the photoacclimative capacity of early-juvenile sporophytes of *Macrocystis pyrifera,* cultivated at different depths. Accepted: Journal of Phycology, doi: 10.1111/jpy.12951

Umanzor, S., Ladah, L. Calderón-Aguilera, L.E. and Zertuche-González, J.A. (2019). Testing the relative importance of intertidal macroalgae as ecosystem engineers across extreme scenarios. Journal of Experimental Marine Biology and Ecology 511: 100–107, doi:10.3354/meps12355

Umanzor, S., Ladah, L. and Zertuche-González, J.A. (2018). Intertidal seaweeds modulate a contrasting response in understory macroalgal and microphytobenthic recruitment. Frontiers in Marine Science 5:296, doi:10.3389/fmars.2018.00296

Umanzor, S., Ladah, L. and Zertuche-González, J. A. (2017). The influence of species, density, and diversity of macroalgal aggregations on microphytobenthic settlement. Journal of Phycology 53 (5), doi: 10.1111/jpy.12565

Umanzor, S., Ladah, L., Calderón-Aguilera, L. E. and Zertuche-González, J.A. (2017). Intertidal macroalgae influence macroinvertebrate distribution across stress scenarios. Marine Ecology Progress Series: 584: 67-77, doi:10.3354/meps12355

Radulovich, R., **Umanzor, S**., Cabrera, R. and Mata, R. (2015). Tropical seaweeds for human food, their cultivation and its effect on biodiversity enrichment. Aquaculture 436: 40–46, doi: 10.1016/j.aquaculture.2014.10.032

ACTIVE PROJECTS AS LEAD INVESTIGATOR

MARINER Program, ARPA-e, Department of Energy (2020-2022)

Assessing kelp nutrient bioextraction capacity in aquaculture farms in the US with implications for conservation and management.

EPSCoR (2021)

Ecophysiological responses of *Fucus distichus* to varying physical and chemical conditions along a glacier to non-glacier gradient.

COLLABORATORS

Artosca, Richard (University of Connecticut), Ask, Erick (DuPont), Augyte, Simona (University of Connecticut), Bailey, David (Woods Hole Oceanographic), Barbery, Kendall (Greenwave), Cabrera, Ruben (Independent researcher), Calderon-Aguilera, Luis (Centro de Investigación Científica y de Educación Superior de Ensenada), Critchley, Alan (Cape Breton University), Diaz, Jhoana (Universidad Autónoma Metropolitana), Goudey, Clifford (Goudey and Associates), Han, Sol (Incheon National University), Hare, Matt (Cornell University), Huang, Mao (Cornell University), Jannick, Jean Luc (Cornell University), Kim, Jang (Incheon National University), Ladah, Lydia (Centro de Investigación Científica y de Educación Superior de Ensenada), Lindell, Scott (Woods Hole Oceanographic Institute), Marty-Rivera, Michael (University of Connecticut), Mata, Rebeca (Universidad de Costa Rica), Pitchford, Steve (National Oceanic and Atmospheric), Ramírez Garcia, Mary Mar (Universidad Autónoma de Baja California), Roberson, Loretta (Marine Biology Laboratories), Robbins, Kelly (Cornell University), Sanchez-Barredo, Mariana (Universidad Autónoma de Baja California), Sandoval, Jose (Universidad Autónoma de Baja California), Shin, Sookkyung (Incheon National University), Smith, Bren (Greenwave), Song, Hyein (Incheon National University), Stegel, Emily (Greenwave), Stekoll, Michael (University of Alaska Fairbanks)

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Education

I am a *cum laude* graduate of Allegheny College with a BSc. (thesis) in Environmental Science/Marine Biology and a Marine Sciences certificate from Duke University.

Employer

November 2010 to present. Director, Department of the Environment and Natural Resources. Native Village of Eyak. Maintain and develop fisheries and wildlife research, environmental research and remediation, renewable energy research and development. Pursue and promote responsible subsistence harvest opportunities. Supervise department staff in Fisheries and Wildlife division, Tribal Renewable Energy Laboratory, Contamination and Remediation Division, and Environmental Division. Coordinate and collaborate with partners (academia, state and federal government, non-profit, tribal, and corporate), consultants, grantors, legislators and students. Negotiate with government officials, draft official responses and comment, manage permitting for research and land use. Set data QA/QC policies and provide final QA/QC on all data. Project PI, and supervise all other PIs. Develop and review organizational policies, and develop enterprise revenue streams.

Committees

-*Prince William Sound Aquaculture Corporation:* Member, Board of Directors, 2016 – present; Finance Committee and Production Planning Committee.

-*AK Dept. of Fish and Game Hatchery Planning:* Member: Prince William Sound Salmon Harvest Task Force; *ex officio* Member, Prince William Sound Regional Planning Team. 2016 – present.

-*Federal Subsistence Board, Southcentral Regional Advisory Council:* 2018 – present.

-*Cordova Fisheries Development Committee:* 2019 - present.

-*Exxon Valdez Oil Spill Trustee Coucil Public Advisory Committee:* Member 2021.

-*Mariculture Task Force: Alaska Native Mariculture Workgroup:* Member 2021. **certification/training**

-Wilderness First Responder

-USFWS Marine Mammal Tagger

-ATV Operator certification

-40-hour HAZWOPER

-Firearms/Bear Safety Instructor

-Alaska DNR Boating Safety Instructor (classroom)

-National Safe Boating Council: Master Instructor Trainer (on-water)

Publications:

M.J. Piche, J.C. Whissel, and J.J. Smith. 2019. Estimating the inriver abundance of Copper River Chinook salmon, 2018 annual report. U.S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program (Study No. 10-503), Anchorage, Alaska.

M.J. Piche, J.C. Whissel, and J.J. Smith. 2018. Estimating the inriver abundance of Copper River Chinook salmon, 2017 annual report. U.S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program (Study No. 10-503), Anchorage, Alaska.

M.J. Piche, J.C. Whissel, and J.J. Smith. 2017. Estimating the inriver abundance of Copper River Chinook salmon, 2016 annual report. U.S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program (Study No. 10-503), Anchorage, Alaska.

M.J. Piche, J.C. Whissel, and J.J. Smith. 2016. Estimating the inriver abundance of Copper River Chinook salmon, 2015 annual report. U.S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program (Study No. 10-503), Anchorage, Alaska.

M.J. Piche, J.C. Whissel, and J.J. Smith. 2016. Estimating the inriver abundance of Copper River Chinook salmon, 2015 annual report. U.S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program (Study No. 10-503), Anchorage, Alaska.

M.J. Piche, J.C. Whissel, and J.J. Smith. 2015. Estimating the inriver abundance of Copper River Chinook salmon, 2014 annual report. U.S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program (Study No. 10-503), Anchorage, Alaska.

Whissel J.C., M.J. Piche and J.J. Smith. 2014. Estimating the inriver abundance of Copper River Chinook salmon, 2013 annual report. U.S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program (Study No. 10-503), Anchorage, Alaska.

Whissel, J.C., M.J. Piche. 2014. Feasibility of Remote Streambed RFID Readers for Long-term Salmon Population Monitoring on the Copper River, Annual Report 2013. U.S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program (Study No. 10-500), Anchorage, Alaska

Whissel, J.C., E. Potapov. 2009. Implantable versus neckband PTTs in swans: What is better? *Microwave Telemetry Bird and Fish Tracking Conference Proceedings.*

Sladen, W.J.; J.C. Whissel. 2007. The winter distribution of Trumpeter Swans in relation to breeding areas: the first neckband study, 1972-1981. *Selected Papers of the Twentieth Trumpeter Swan Society Conference.* 117-125.

Wissinger, S.A., J.C. Whissel, and C Eldermire. 2006. Predator defense along a permanence gradient: roles of case structure, behavior, and developmental phenology in caddisflies. *Oecologia* 148:667-678.

Wissinger, S.A., C. Eldermire and J.C. Whissel. 2004. The role of larval cases in reducing aggression and cannibalism among caddisflies in temporary wetlands. *Wetlands* 24(4): 777-783.

Maniates, M.F., J.C. Whissel. 2000. Environmental studies: the sky is not falling. *BioScience.* June: 509-517.

Collaborators:

Matthew J. Piche and Jason J. Smith, collaborators 2016-2020

11. SUGGESTED REVIEWERS (for new project proposals only)

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12. APPENDICES

Farmer partner letters of support are included as Appendix A.

Consortium Information is included as Appendix B.

Project 22220302 Proposal Review – PI Responses is included as Appendix C.

A detailed budget workbook is provided using the EVOSTC Excel template.

Requested audited financial statements are submitted as nine separate PDF documents: three each for leadership team institutions PWSSC, AFDF, and NVE, as required. Financials are not required for leadership team member ASG, which is co-funded by NOAA and housed at the University of Alaska.