Eelgrass & Aquaculture

'State of the Science' Workshop

SUMMARY REPORT

JANUARY 2024
OLYMPIA, WA

Pacific Shellfish Institute

PACIFIC STATES MARINE FISHERIES COMMISSION
IDAHO • OREGON • ALASKA
WASHINGTON • CALIFORNIA

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Eelgrass & Aquaculture 'State of the Science'
WORKSHOP SUMMARY

Contents

List of Acronyms

CA	California
CEMP	California Eelgrass Mitigation Policy
eDNA	Environmental deoxyribonucleic acid
EFH	Essential fish habitat
EGS	Early growing season
ESA	Endangered Species Act
GIS	Geographic information system
ha	Hectare
HAPC	Habitat area of particular concern
HDPE	High-density polyethylene
LGS	Late growing season
m	Meter
mm	Millimeter
MSA	Magnuson-Stevens Fishery Conservation and Management Reauthorization Act
NGS	Non-growing season
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OR	Oregon
PSI	Pacific Shellfish Institute
PSMFC	Pacific States Marine Fisheries Commission
TEK	Traditional Ecological Knowledge
UAV	Unmanned aerial vehicle
UC	University of California
USDA	United States Department of Agriculture
USDA-ARS	United States Department of Agriculture, Agricultural Research Service
UW	University of Washington
WA	Washington
WCR	West Coast Region
WDFW	Washington Department of Fish and Wildlife
WDOE	Washington State Department of Ecology

EXECUTIVE SUMMARY

On January 17, 2024, Pacific Shellfish Institute (PSI) convened over 100 researchers and agency, tribal, shellfish industry, and environmental organization representatives for an all-day workshop in Olympia, Washington, to share findings from a multi-year research effort on the interactions of eelgrass and aquaculture – particularly oyster culture – in multiple locations across Washington, Oregon, and California.

Specifically, the workshop sought to:

- Connect scientists, resource managers and shellfish farmers to disseminate study results to date.
- Increase understanding about eelgrass and shellfish aquaculture interactions in environments along the west coast.
- Solicit input on the potential usefulness of this research to inform regulatory decision making and seek ideas on additional research needs and data gaps.

Twelve researchers presented the 'state-of-the-science' on the following topics:

- Field research on the interactions of eelgrass communities and oyster aquaculture
- Environmental DNA (eDNA) complementarity
- Fish diet response to eelgrass and aquaculture operations
- Shellfish aquaculture farms as foraging habitat
- Mapping eelgrass with aerial imagery
- Economics of oyster aquaculture gear types

At certain junctures following presentations, participants engaged in exploratory discussions prompted by the following questions:

- Is this information useful for regulatory decision making?
- Are there management implications of this work? If yes, what might they be?
- What are the data gaps for this research area/what information is needed to make more informed decisions?

The majority of workshop participants indicated they believe these studies support a better understanding of the value of habitats for managed fish and invertebrate species and provide useful information for management and regulatory decision making. Many suggestions for information needs and future research questions were shared by participants related to aquaculture operations, habitat and species interactions, invasive species, management and policy, climate change impacts, and similar.

This summary presents an overview of the presentations and group discussions from the "Eelgrass and Aquaculture: State of the Science" Workshop.

I. BACKGROUND

Oyster culture has overlapped with eelgrass habitat for more than a century. Ensuring shellfish aquaculture remains environmentally and economically sustainable is a primary concern and challenge for resource managers and the commercial shellfish industry. Improved understanding of the interactions between eelgrass and oyster culture, and the ecological function of these habitats for managed fish and invertebrate species, will aid decision making.

Why Does it Matter?

Eelgrass provides important biological, physical, and economic value. For example, it creates structured habitat in areas of loose sand or silt; meadows are nursery areas for many taxa and are important juvenile habitat for numerous fish species; it supports key ecological functions in coastal and estuarine ecosystems; and it can serve as a biological indicator of ecosystem health.

Because of such functions, eelgrass is designated a habitat area of particular concern (HAPC) within essential fish habitat (EFH) for various federally managed fish species, as pursuant to the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (MSA).

Eelgrass is also afforded protections under various state laws along the west coast of the United States:

- Washington:
  - The Washington Department of Fish and Wildlife (WDFW) designated seagrass meadows as habitats of special concern (WAC 220-110-250) via its statutory authority relating to construction projects in state waters (RCW 77.55.021).
  - The Washington State Department of Ecology (WDOE) designated eelgrass areas as critical habitat (WAC 173-26-221) via its statutory authority associated with implementing the state's Shoreline Management Act (RCW 90.58).
- Oregon:
  - Protection and management of eelgrass is structured within the Statewide Planning Goal 16 for Estuarine Resources (OAR 660-015-0010(1)).
- California:
  - Several state agencies use the California Eelgrass Mitigation Policy (CEMP) (Region 2014) for eelgrass management. The National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) adopted the CEMP and implementing guidelines, including the goal of "no net loss" of eelgrass habitats in California[1] .

[1] Gilkerson, W.A., and K.W. Merkel. 2014. Humboldt Bay Eelgrass Comprehensive Management Plan. Prepared for Humboldt Bay Harbor, Recreation and Conservation District.

2017 Washington Eelgrass and Shellfish Aquaculture Workshop

In April 2017, the NMFS West Coast Region (NMFS WCR) convened an all-day workshop[2] to discuss management of native eelgrass and shellfish aquaculture to:

- Increase understanding about eelgrass and shellfish aquaculture interactions.
- Determine where and why inconsistencies in eelgrass management related to shellfish aquaculture exist.
- Develop a path forward for addressing eelgrass management inconsistencies in Washington.

Outputs of this workshop included recommendations for future actions to achieve consistency in management, and the identification of future research questions and needs. These outputs were the catalyst for this collaborative research effort.

Table 1. Research needs from *NMFS WCR 2017 Washington Eelgrass and Shellfish Aquaculture Workshop Report*, adapted from "Table VI. Recommendations for Future Actions to Achieve Consistency in Management."

Consideration	Management Question
Ecosystem function (eelgrass & aquaculture)	- What is provided by shellfish aquaculture, and how does it compare to eelgrass? - How can we best measure and monitor ecosystem function? - How can we examine a broader spatial and temporal scale? How can we account for the fact that eelgrass beds are not static?
Eelgrass function	- What oyster culture methods, and extent of aquaculture is compatible with healthy eelgrass function?
Healthy eelgrass	- What are ideal bottom culture densities and/or aquaculture gear spacing to support healthy eelgrass?
Ecological value	- How do current eelgrass management metrics (e.g., density and percent cover) correspond? - Does eelgrass reduce effects of ocean acidification near natural shellfish beds and shellfish aquaculture sites?

Current Research Project: Assessment of Ecological Function and Interactions of Oyster Culture and Eelgrass

This project is a coast-wide assessment of eelgrass response to shellfish culture practices to better understand the value of habitats for managed fish and invertebrate species, including juvenile salmon (*Oncorhynchus* species), Dungeness crab (*Metacarcinus magister*) and English sole (*Parophrys vetulus*). In collaboration with shellfish farms, research partners are assessing

[2] National Marine Fisheries Service West Coast Region. 2017. Washington Eelgrass and Shellfish Aquaculture Workshop Report. Seattle, Washington. https://media.fisheries.noaa.gov/dam-migration/wa_eelgrass_and_shellfish_aquaculture_workshop_report_final_11-03-17.pdf

the interaction of eelgrass with various oyster culture systems, and the ecological functions of these habitats.

An important goal of this research is to support regulatory agencies in taking a more holistic approach to permit decisions related to shellfish farm siting and aquaculture-eelgrass interactions that depart from the current 'one-off' approach to permitting.

Studies were conducted from 2019 through 2023 in various locations in Washington, Oregon, and California. The biological, physical, and monetary parameters measured by the studies across different habitat types include (Figure 1):

- Amount of eelgrass
- Production of oysters
- Nekton abundance
- Nekton behavior
- Fish diets
- Shorebirds
- Burrowing shrimp
- Water properties
- Drone and ground-based mapping
- Oyster gear type costs
- Management scenario relative costs

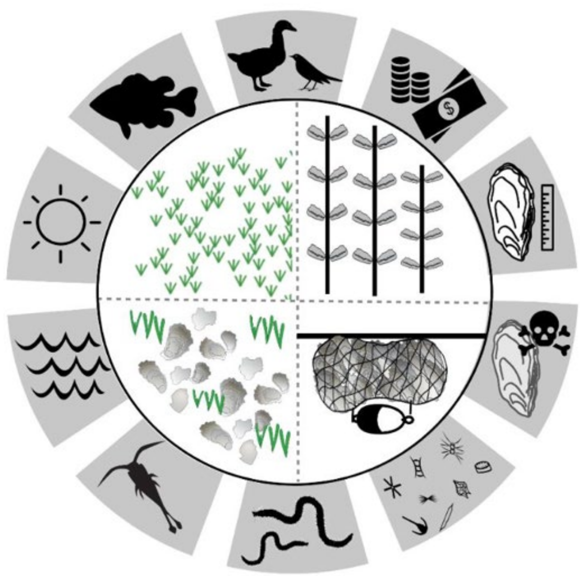

Figure 1. Infographic depicting the biological, physical, and monetary parameters measured by the studies across different habitat types. Infographic by Katie Houle, PSI, using Piktochart.

Study Methodologies and Terms

General research study design parameters and methodologies were described at a high level to provide foundational understanding of terms used by researchers in their 'state-of-the-science' presentations.

Study Sites

Study sites included Samish Bay, Hood Canal, Grays Harbor, and Willapa Bay in Washington; Tillamook Bay in Oregon; and Humboldt and Tomales Bays in California (Figure 2).

Figure 2. Study site locations.

Habitat Mosaic Study Design

Many field studies utilized a habitat mosaic design to compare the effects of oyster culture in no eelgrass, sparse eelgrass, and dense eelgrass conditions (Figure 3). Ecological samples were taken using transects and shoot collection, video and minnow traps, and seine net tows.

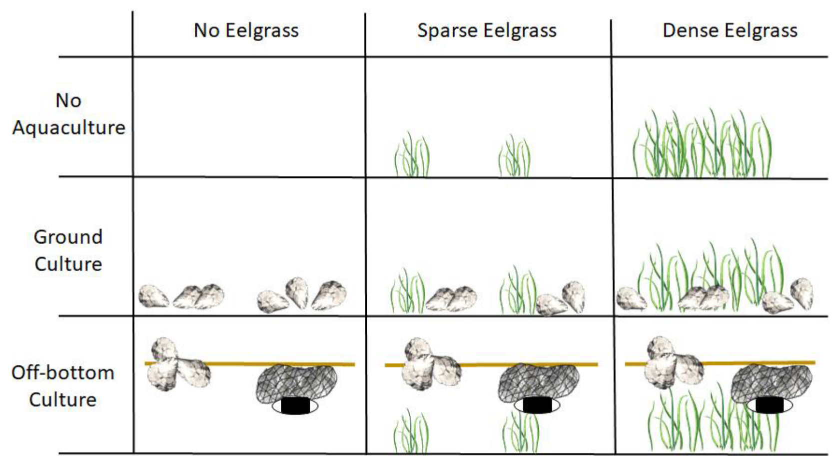

Figure 3. Habitat mosaic study design schematic.

Methods for Oyster Culture

- *Ground culture* refers to oysters growing directly on the sediment, harvested mechanically or by hand.
- *Off-bottom culture* refers to gear affixed above the sediment surface. This can include longlines, racks, baskets, flip-bags and other containers.
- *Suspended culture* refers to gear that hangs down from the surface (versus lifted on racks or stakes), such as lantern nets and floating bags.

Oyster Culture Gear Types

- *Longline* is a variation of off-bottom culture where lines with oysters are suspended a few feet off the seafloor.
- *Flip-bags* are a dynamic suspended system of high-density polyethylene (HDPE) mesh bags clipped to anchored lines approximately one meter (m) above the substrate.
- *Cages/bags* are HDPE or wire mesh containers secured to lines, floats or rafts, or directly to the seafloor.

Project Partners

Funding Partners:

- Pacific States Marine Fisheries Commission (PSMFC)
- National Oceanic and Atmospheric Administration (NOAA)

Research Partners:

- Pacific Shellfish Institute (PSI)
- University of Washington (UW)
- Confluence Environmental Company
- University of California, Santa Cruz (UC Santa Cruz)
- United States Department of Agriculture, Agricultural Research Service (UDSA–ARS)
- NOAA Northwest Fisheries Science Center (NWFSC)

Collaborating Farms and Associations:

- Brady's Oysters
- Chetlo Harbor Shellfish
- Goose Point Shellfish Farm and Oyster
- Hama Hama
- Heckes Oyster Company
- Hog Island Oyster Company
- Jolly Roger Oyster Company
- Northern Oyster Company
- Pacific Coast Shellfish Growers Association
- Pacific Seafood
- R&B Oyster Company
- Rock Point Oysters
- Taylor Shellfish
- Willapa-Grays Harbor Oyster Growers Association

II. WORKSHOP OVERVIEW

PSI hosted an all-day workshop on January 17, 2024, for more than 100 participants in Olympia, Washington, to share findings from a multi-year research effort examining the interactions of eelgrass and aquaculture – particularly oyster culture – in multiple locations across Washington, Oregon, and California (see Appendix A for workshop agenda). Specifically, the workshop sought to:

- Connect scientists, resource managers and shellfish farmers to disseminate study results to date.
- Increase understanding about eelgrass and shellfish aquaculture interactions in environments along the west coast.
- Solicit input on the potential usefulness of this research to inform regulatory decision making and seek ideas on additional research needs and data gaps.

Research partners delivered thirteen succinct presentations on the various components of this collaborative research effort, sharing the current state of the science (see Appendix D for speaker biographies). At two points in the program, participants engaged in group discussion to explore potential management implications of this research and identify possible data gaps and future research needs. Participant discussions were prompted by the following questions:

- Is this information useful for regulatory decision making?
- Are there management implications of this work? If yes, what might they be?
- What are the data gaps for this research area/what information is needed to make more informed decisions?

Summaries of the studies and the following discussions are provided in the next section.

III. STATE OF THE SCIENCE

Eelgrass Trait Response to Intertidal Stress and Aquaculture

Presented by Jen Ruesink, University of Washington

Pacific oyster (*Crassostrea (Magallana) gigas*) aquaculture and eelgrass (*Zostera marina*) overlap on intertidal flats of the U.S. west coast where heating, freezing, and drying constitute stressors that set the upper limit for eelgrass survivability. Twelve study sites in Tillamook, Willapa, Grays Harbor, Samish, and Hood Canal included beds spanning one meter vertically around mean lower low water. The traits of eelgrass were determined according to the habitat mosaic design (eelgrass [sparse, dense] x culture [none, ground, off-bottom]), while accounting for tidal elevation. Traits were divided into those related to resistance (above-ground size, rhizome biomass) and recovery (flowering, branching, and rhizome extension). Results were not always consistent by season, but when traits responded they did so in the following manner:

- At higher tidal elevations, resistance traits declined, along with the recovery trait of branching, whereas flowering increased.
- While above-ground size declined in culture, rhizome biomass did not.
- Recovery traits of flowering, branching, and rhizome extension increased in ground culture.
- In off-bottom culture, impacts on recovery traits differed by elevation, with flowering reduced at higher elevations and rhizome extension reduced at lower elevation.

These results address the resilience of eelgrass, rather than the amount present on oyster beds. Relative to intertidal stress, ground culture promoted resilience and off-bottom culture had less effect.

Separately, 25 millimeter (mm) Pacific oysters were outplanted at ten sites in Willapa Bay, Samish Bay, and Hood Canal to determine growth and survival across the habitat mosaic design (eelgrass [none, sparse, dense] x culture [ground, off-bottom]). Oysters survived better and had higher meat weight (per shell height) in off-bottom relative to ground culture, where survival declined in siltier sediments. In contrast, oysters did not improve performance with eelgrass.[3]

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[3] The results of this study are published: Ruesink JL, Houle K, Beck E, Boardman FC, Suhrbier A, Hudson B. 2023. Intertidal growout technique, not eelgrass (Zostera marina), influences performance of Pacific oysters (Magallana gigas). Aquaculture Research, vol. 2023, Article ID 6621043, 13 pages, https://doi.org/10.1155/2023/6621043

Nekton Community Response to Gradients of Eelgrass and Different Oyster Aquaculture Methods

Presented by Kelly McDonald, Confluence Environmental Co.

In ecology it is generally understood that nekton communities respond to the presence of seagrasses, as well as shellfish aquaculture gear.[4,5,6] This collective sampling and analysis across a mosaic of habitats sought to further understand species use of seagrass and aquaculture environments. The habitat mosaic experimental design included a gradient of native eelgrass (*Zostera marina*) densities in the presence and absence of Pacific oyster (*Crassostrea (Magallana) gigas*) aquaculture gear, allowing for analysis related to nekton community response to both types of habitats.

Using nekton species data collected with seine nets from 11 sites in Washington, multivariate community dissimilarity values were calculated to assess distinctions in species abundance and presence between habitats within a given site. Dissimilarity values comparing dense eelgrass habitats with no aquaculture, and mudflat habitats with no aquaculture, to each of the other habitats in the mosaic design were extracted for visualization and analysis. These values compare communities to two meaningful endpoints in estuarine systems that are known to drive nekton presence.

Relative to the dense eelgrass habitat, there is a clear response to eelgrass density when aquaculture is absent. The communities in a sparse eelgrass habitat were intermediate between the mudflat and dense eelgrass habitats. With either ground or off-bottom culture present, the response of the nekton community across the eelgrass density gradient was moderated and less apparent than when aquaculture was absent. Such relationships are also seen when comparing to a mudflat habitat. These results suggest that the presence of oysters in ground culture and the presence of gear associated with off-bottom culture affect the complement of species present, regardless of eelgrass density. Nonetheless, the habitats provided by eelgrass and aquaculture are not entirely redundant. When the primary structure on a tidal flat is provided by oysters and/or aquaculture gear, the community in this habitat is distinct from that in a dense eelgrass habitat. Assessment of specific species associations and behaviors helps to elucidate what may be driving these differences.

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[4] Hosack, G. R., B. R. Dumbauld, J. L. Ruesink, and D. A. Armstrong. 2006. Habitat associations of estuarine species: Comparisons of intertidal mudflat, seagrass (Zostera marina), and oyster (Crassostrea gigas) habitats. Estuaries and Coasts 29(6):1150–1160.

[5] Ruesink, J. L., C. Gross, C. Pruitt, A. C. Trimble, and C. Donoghue. 2019. Habitat structure influences the seasonality of nekton in seagrass. Marine Biology 166(6):75.

[6] Theuerkauf, S. J., L. T. Barrett, H. K. Alleway, B. A. Costa-Pierce, A. St. Gelais, and R. C. Jones. 2022. Habitat value of bivalve shellfish and seaweed aquaculture for fish and invertebrates: Pathways, synthesis and next steps. Reviews in Aquaculture 14(1):54–72.

Seasonality of Nekton Species Use of Intertidal Estuarine Habitats, and Response to Eelgrass and to Ground and Off-bottom Culture

Presented by Fiona Boardman, University of Washington

This work took place in six sites in Willapa Bay, using the habitat mosaic sampling design with three levels of oyster culture (no culture, ground culture, off-bottom culture) and three levels of eelgrass (no eelgrass, sparse eelgrass, and dense eelgrass). Researchers used video and seine methods to sample nekton use of the nine distinct habitat types, and sampled in both spring and summer to determine the role of seasonality in nekton community and habitat use.

Large seasonal differences in nekton communities were found in Willapa Bay, with the most abundant taxa in spring being juvenile English sole and hippolytid (i.e., "grass") shrimp, while shiner perch were the most abundant taxon during the summer. Overall, nekton communities did not respond to seagrass and oyster culture in the same ways, during either season. Researchers identified three groups of taxa based on their habitat associations: 1) taxa associated specifically with eelgrass, 2) taxa associated with vertical habitat generally (both off-bottom culture and eelgrass), and 3) taxa found in habitats lacking vertical structure, either in bare mudflat or with ground culture. It can be concluded that the presence of oyster culture in eelgrass did not generally deter taxa from using eelgrass or mudflat habitats, and that maintaining a mosaic of habitat types (eelgrass, mudflat, ground-culture, off-bottom culture) supports a large diversity of taxa across different life stages and seasons.[7]

Nekton Response to Flip-Bags Co-located with Eelgrass

Presented by Katie Houle, Pacific Shellfish Institute

Shellfish farmers in Washington State have been exploring the use of novel intertidal aquaculture methods to maximize production per acre of high-quality single oysters. The interactions of biological communities with mixed flip-bag oyster culture, eelgrass and mudflat habitat have not been comprehensively explored. This study assessed nekton use of six intertidal flip-bag farms co-located with eelgrass *Zostera marina* in three shellfish growing regions in Washington State: Willapa Bay, Hood Canal and Samish Bay.

In 2020 and 2021, nekton communities were sampled in four habitat types: flip-bags with eelgrass, flip-bags without eelgrass, eelgrass with no culture, and bare mudflat. Sampling occurred in spring and summer using a modified seine net to collect nekton >5mm in size and using underwater GoPro cameras set to record for two minutes every 10 minutes during the diel flood tide through high slack tide. Nekton abundance, taxa richness,

[7] The results of this study are published: Boardman, F. C., Subbotin, E. R., & Ruesink, J. L. (2023). Nekton use of co-occurring aquaculture and seagrass structure on tidal flats. Aquaculture Environment Interactions, 15, 307–321. https://doi.org/10.3354/AEI00467

community composition and individual species associations by habitat type were analyzed and compared between seine net tows and video observations. Transiting and foraging behavior of shiner perch by habitat type and season (spring, summer) for Puget Sound farm sites were also analyzed.

Eelgrass presence had the strongest effect in the spring on nekton abundance, taxa richness, community assemblage and individual species associations, including crangon shrimp, bay pipefish, three-spine stickleback, and saddleback gunnel. Summer video sampling indicated flip-bags may increase abundances of certain species, including shiner perch, with overall more taxa present. Results from summer seine net tows indicate an effect of flip-bags on community assemblage with one species (arrow goby) preferentially associated with the benthic environment below flip-bags at Willapa Bay sites only. Transiting was the most common behavior observed in video, followed by foraging, and then resting. Neither eelgrass or flip-bag presence had a statistically significant effect on transiting or foraging behavior of shiner perch, however more transiting occurred with eelgrass present in spring, while more foraging activity occurred with flip-bags in summer. In summary, both eelgrass and flip-bags have seasonally different effects on nekton communities. Flip-bags sited in eelgrass do not appear to deter species associated with eelgrass beds. Most nekton utilize the broader habitat mosaic of mudflat, eelgrass, and flip-bag aquaculture.

Trophic Level Responses to Different Longline Densities and Clustering

Presented by Maria Garcia, University of Washington

This study examined how longline density and aisle width could be altered to mediate effects on eelgrass. Two questions were asked: 1) how does altering the density of longlines and the aisle width between them affect eelgrass presence, and 2) do these effects extend to higher trophic levels?

Longline density and aisle width were altered at two sites in Willapa Bay, Washington. Density was altered by having reference sites with no longlines, normal density, and half density. Another set of conditions kept the density of longlines but altered the spacing between them by clustering sets of longlines close together with larger aisles. This set of conditions was designed through collaboration with oyster farmers to test options which would be economically viable to implement.

Response variables spanned four trophic levels and included eelgrass, epiphyte load, epifauna load and community structure, and nekton abundance and community structure. Lower longline densities allowed for more eelgrass. However, when the overall density of longlines remained the same, effects on eelgrass were reduced when longlines were clustered (increased aisle width). Despite changes in eelgrass, neither longline density nor aisle width extended to higher trophic levels. Only the epifaunal community differed significantly in response to aisle width.

Eelgrass Recovery Following Disturbance from Mechanical Shellfish Harvest

Presented by Fiona Boardman, University of Washington

This study examined the recovery of eelgrass following disturbance via mechanical harvest on six adjacent ground-culture oyster beds in Bruceport, Washington (Willapa Bay). The beds were harvested on a rotating schedule, providing the opportunity to study how disturbance timing affects eelgrass recovery mechanisms and potential.

Disturbance timing was classified using four categories: early growing season (February - April), late growing season (May - September), non (slow) growing Season (October - January), and “control” (undisturbed beds for 12+ months beginning in September). Early growing season (EGS) is characterized by seed germination and clonal branching, while late growing season (LGS) is characterized by shoots growing longer. The non-growing season (NGS) is characterized by a period of slow growth and shoot maintenance. Eelgrass can reproduce via flowering and creation of seeds in summer months that germinate the following spring, or by clonal reproduction of shoots (i.e., branching). Seed banks are only viable for one year, and shoots grown from seed do not typically flower until their second year.

Results demonstrate control beds have the highest eelgrass density, and beds disturbed during the EGS or NGS periods have the greatest potential for recovery. EGS-disturbed beds had an elevated contribution of seedlings to recovered shoots, while LGS-disturbed beds saw poor recovery overall. Analysis of spring seedling density revealed that the number of flowering shoots the previous summer and presence of shell cover (~20% coverage) both had positive effects on seedling density. Thus, seedlings play an important role in shoot density recovery, and are the primary method of recovery when beds are disturbed to the point of bareness (i.e., no adult shoots to branch or make new seeds). However, seedlings can only contribute to recovery if the disturbance occurs during NGS or EGS periods, and if there is a seedbank present on the bed (i.e., mature shoots flowered the previous summer). Lastly, leaving clusters of adult shoots, which will create clonal shoots and contribute to a seed bank, also aids recovery potential by allowing for two mechanisms of recovery.

Discussion Session #1

Following this suite of presentations emphasizing field research, participants were invited to engage in an informal polling exercise using *Slido* to provide feedback on several prompting questions. It was noted that participation was voluntary, anonymous, and that no response put forward would commit any individual, organization, or agency to a position. Poll results were displayed in real-time to stimulate further group discussion. Participants reflected on the feedback acquired via the polls and contributed additional ideas. Results are summarized below. Direct outputs of the *Slido* polls are in Appendix B.

Question: Are there management implications of this work?
Response:
- Yes: 58 votes (84%)
- No: 2 votes (3%)
- I don't know: 9 votes (13%)

Question: What are data gaps for this research area/what information is needed to make more informed decisions?
Summarized take-aways from poll responses and follow on discussion:
- To support improved management decision making, it is critical to determine:
  - What is the environmental baseline the community/region is trying to manage to?
  - What are the species/habitat/economic objectives the community/region is managing for?
- Various federal and state laws are working to protect numerous species and habitats. Sometimes these regulations are in competition. Simultaneously, aquaculture provides a significant human food source and contributes to local economies. All needs must be considered and balanced to the extent possible. This may require an adaptive management approach.
- Topic areas and questions for future research:
  - Can this research inform or have bearing on related research being conducted for species listed under the Endangered Species Act (ESA), specifically salmonids?
  - When might oyster harvest activities and timing be important for eelgrass recruitment and/or survivability? Is it possible to couple aquaculture techniques to jumpstart eelgrass recovery?
  - How can managers best balance ecosystem and industry needs, while understanding and accounting for interactions between eelgrass and aquaculture?
  - What are pest and invasive species interactions and impacts on eelgrass and oyster culture operations, specifically European green crab and burrowing shrimp?

- Are there seasonal differences in the interactions between oyster aquaculture and eelgrass?
- What are the impacts of climate change, such as ocean acidification and warming, and heat dome events?
- What are potential management implications when eelgrass beds are created or expand due to the presence of gear? Should oyster aquaculture habitat be considered EFH, given its role in recruitment of Dungeness crab and other species of significance?
- How can the cumulative impacts of farming, climate change, invasive species, overfishing, and extreme tidal events to eelgrass be measured?

eDNA Complementarity with Other Observations of Fish in California and Washington Aquaculture, Eelgrass, and Mudflats

Presented by Rachel Meyer, UC Santa Cruz

Environmental DNA (eDNA) is the DNA shed by organisms into the environment. It can be transported in water, lasting days in the area, and it can bind to sediment, lasting several weeks. Researchers surveyed fish and broad eukaryotic diversity using multilocus metabarcoding, a technique to survey the myriad different organisms that have shed DNA into a sediment sample using different primer sets to target certain groups. Broad eukaryotes can paint a holistic picture of habitat similarity that may help explain the environmental differences that correlate with different fish species occupancy.

The research team investigated community similarity between regions and between spring and summer seasons, focusing on 195 sediment samples from mudflats, eelgrass, and oyster aquaculture habitats along the Pacific coast. Variables of habitat, bay, and season all significantly separated communities detected by eDNA, with stronger differences found in the spring compared to summer. Some of the most common fish found in video and seine surveys of the same sites are indeed the most prevalent fish in eDNA samples. There are several species that evade morphological surveys but show strong presence in eDNA, such as Pacific herring. Conversely, several fish are first observations, meriting scrutiny of eDNA accuracy. The team is working together to improve accuracy in eDNA results to better illuminate fish use of these different habitats.

Fish Diet Response to Eelgrass and Oyster Aquaculture

Presented by Bob Oxborrow on behalf of Jason Toft, University of Washington

The main objective was to examine foraging and prey characteristics of juvenile fish species that were collected at oyster aquaculture and eelgrass habitats. 288 fish diets were processed over the course of three years (2020-2022), across five estuaries in Washington and Oregon (Willapa Bay, Hood Canal, Grays Harbor, Samish Bay, Tillamook

Bay), and focused on six fish species (shiner perch, staghorn sculpin, Pacific sanddab, English sole, starry flounder, three-spined stickleback). Oyster culture types included ground and off-bottom (e.g., longline, flip-bags). The number of diets for analyses depended on the fish species and counts that were captured, and therefore varied across estuaries and habitats. Some fish were more transient and located in the water column (i.e., shiner perch and sticklebacks), while others were more resident and demersal (i.e., staghorn sculpin, English sole, Pacific sanddab, and starry flounder).

Laboratory work included dissection of fish stomachs, and identification, count and weight of prey taxa. Three metrics for analyses were examined: prey mass, prey source, and prey assemblage. Prey mass was determined by comparing measurements of instantaneous ration, which is the weight of prey taxa divided by the weight of the fish. Measurements of instantaneous ration were equal at eelgrass and aquaculture, signifying that fish are acquiring an equal amount of prey mass at the two habitats. Prey source was analyzed by comparing the numerical proportion of grouped epifauna and infauna taxa. Fish fed more on epifauna sourced prey at eelgrass, and more on infauna sourced prey at aquaculture. Prey assemblages showed that most of the epifauna prey were harpacticoid copepods, small crustaceans known to be associated with eelgrass, and most of the infauna prey were other crustaceans such as tanaids and Corophiidae amphipods, as well as bivalves. Overall, results show that fish are feeding equally on prey mass at eelgrass and aquaculture, but feed differently on the diversity of prey and their source habitats.

Shellfish Aquaculture Farms as Foraging Habitat for Nearshore Fishes and Crabs in Puget Sound

Presented by Karl Veggerby, Anchor QEA

Stable isotope mixing models were used to estimate the percent diet originating from either a natural bottom habitat (eelgrass meadows), farm habitat (oyster farms), or pelagic planktonic sources for several species of nearshore fish and crab in two areas of North Puget Sound, Washington. Results indicate that several species of nearshore fish derive a significant proportion of their diets from farm areas, while crabs derive most of their diets from eelgrass habitat. [8]

The analysis provides unique insights into the functional role of different nearshore habitat types for key nearshore consumers. Aquaculture habitat appeared to provide unique foraging opportunities for certain mobile species within this system. This, in turn, likely benefits the system's biodiversity in some capacity, despite the potential impact on eelgrass, which was also estimated to provide key foraging opportunities. All three potential habitat diet sources were estimated to be important for at least one species,

[8] The results of this study are published: Veggerby Karl B., Scheuerell Mark D., Sanderson Beth L., Kiffney Peter M. (2024). Stable isotopes reveal intertidal fish and crabs use bivalve farms as foraging habitat in Puget Sound, Washington. Frontiers in Marine Science, 10. https://doi.org/10.3389/fmars.2023.1282225

which highlights the benefits of having a diverse array of habitat types within a nearshore area. Having a diverse set of habitat types within a nearshore area provides foraging and refuge to a wide range of species. While farm habitats cause localized disturbance to native nearshore habitat, they also appear to avail a wide range of foraging opportunities.

Landscape-scale Mapping of Eelgrass and Aquaculture: Distributions, Interactions, and Historical Comparisons

Presented by Brett Dumbauld, United States Department of Agriculture and Nate Lewis, Oregon State University

Remote sensing tools continue to improve and have become increasingly valuable to map and assess interactions between shellfish aquaculture and submerged aquatic vegetation at the estuarine landscape scale. This is particularly true for United States west coast estuaries where shellfish aquaculture often occurs across relatively large intertidal areas that can now be more accurately assessed via high resolution digital photography taken during low tides from several platforms including satellites, fixed-wing aircraft, and/or unmanned aerial vehicles (UAVs) depending on the spatial and temporal scale of the project.

USDA–ARS researchers first developed geographic information system (GIS) with data layers for eelgrass and active aquaculture distributions in Willapa Bay, Washington across three years in the mid-2000's. Data was collected using an extensive ground survey and orthoimagery (4-band) captured from fixed-wing aircraft. Information on active aquaculture boundaries, aquaculture bed type and bed use were collected via interviews with shellfish growers. These two data layers were then used to quantify the structured habitats and model their interaction at the estuary scale.

These historical data served as a baseline for comparisons with updated GIS layers of eelgrass and active aquaculture distribution based on new 2020 orthoimagery. This higher resolution imagery was captured during ideal low tide conditions and allowed for improved classification of eelgrass as well as visible evidence of culture, equipment, and physical use of the culture beds that was then cross-checked and verified with industry. Overall, eelgrass coverage estimates in Willapa Bay declined slightly from 5,938 hectare (ha) in 2009 to 5,551 ha in 2020. While active oyster aquaculture increased from 1,764 ha to 3,137 ha, this can largely be attributed to better definition of "active" aquaculture, since "total" oyster aquaculture was also estimated to be 3,474 ha in 2005. These new estimates allow for the interaction between eelgrass and aquaculture to again be quantified throughout the estuary and more comprehensive estimates of eelgrass distribution to be made considering environmental gradients and/or culture/harvest methods.

The Best Methods to Map Eelgrass and How to Use Drone Imagery to Supplement These Methods and Improve Accuracy

Presented by Phil Bloch, Confluence Environmental Co.

Between 2020 and 2024 researchers examined best practices and future opportunities for using small UAV (sUAV) to support mapping and monitoring eelgrass (*Zostera marina*) on the U.S. west coast. Environmental monitoring and regulatory requirements create a demand for generating accurate depictions of eelgrass habitat and condition. Prior to the use of sUAV technology, intertidal surveys were primarily completed using transect surveys where a survey would move along a transect perpendicular to shore and record points where the survey is within an eelgrass bed. This technique creates useful, but often low-resolution depictions of eelgrass beds. By mapping using sUAV, field scientists can create more complete and higher resolution depictions of eelgrass beds that are useful for both regulatory mapping and detecting change over time.

When mapping eelgrass using sUAV equipment, the data is typically collected using an automated flight plan so that many still images are collected. These pictures are combined to create an orthophoto and topographic map of the study area. These data can then be interpreted using automated techniques or with a human interpreter to convert the imagery into data representing eelgrass habitat. Several key variables affect the quality of aerial imagery and subsequent mapping outputs. These variables include the sUAV equipment, the target resolution, the overlap between images, timing of field data collection, weather, tidal elevation and whether there are competing features that are similar color on the landscape. In general, eelgrass mapping is best during overcast weather conditions, when there is little wind, early in the eelgrass growing season (typically May or June) and when tides are sufficiently low to expose eelgrass and/or eelgrass is floating on the water's surface. Target resolution can vary, though mapping such that pixels represent approximately one square inch of ground area provide high quality maps.

Advantages to this type of mapping include that the error or confidence in the data can be established by generating a misclassification table that characterizes the overall accuracy of the mapped survey area. Further, because data is archived, it allows for re-evaluation as techniques or technologies for image interpretation improve or as research questions emerge.

Describing Changes to Eelgrass Cover and Density from Aquaculture Activities at the Farm Scale

Presented by Phil Bloch, Confluence Environmental Co.

Mapping eelgrass beds allows for change detection and mapping of interactions between stressors and eelgrass beds. Recent examples include mapping of impact and recovery during an extreme high temperature 'heat dome' event that occurred during extreme low tides. Significant eelgrass loss was documented in higher tidal elevations in Samish Bay. Intertidal activities such as boat activities and installation of oyster cultch piles were also documented using aerial imagery. Small scars in eelgrass areas appear to recovery quickly (e.g., in a single season) whereas installation of oyster cultch in an intertidal area may create long-term impacts to eelgrass. sUAVs have also been used to map and describe interactions between aquaculture activities and eelgrass. Complementary mapping of aerial cover and shoot density quadrats appears to demonstrate that some forms of off-bottom and floating aquaculture have minimal or no significant adverse effect on eelgrass habitats.

Economics: Costs and Profitability of Different Gear Types for Ground and Off-bottom Oyster Aquaculture

Presented by Olivia Horwedel, PSI / UW

This presentation highlighted some of the findings from the report, Oyster Aquaculture: Cost Differentials of Gear Types and Profitability.[9] In 2018, studies demonstrated that oyster aquaculture was the most valuable form of marine aquaculture in the United States, with production of oysters valued at over $200 million annually. As the industry continues to grow in value, producers will look at growing oysters in a way that is not only profitable but also factors in the influence of various gear types on nearby environments. This report uses existing literature, an online-survey, and interviews to analyze the costs of labor and equipment of alternative oyster grow out gear types. It further reviews the various gear types, addresses the profitability of growing oysters using different gear types, illustrates the various expenses associated with growing oysters, and provides cost estimates for on-bottom and off-bottom growing methods.

[9] URL to access report: https://www.pacshell.org/pdf/Horwedel_Costs.pdf

Discussion Session #2

Following this second series of presentations, participants were again invited to engage in an informal polling exercise using *Slido* to provide feedback on a similar set of prompting questions. As before, poll results were displayed real-time to stimulate further group discussion. Participants reflected on the feedback acquired via the polls and contributed additional ideas. Results are summarized below. Direct outputs of the *Slido* polls are in Appendix B.

Question: Can aerial mapping and analysis of eelgrass densities be useful in regulatory decision making?
Response:
- Yes: 45 votes (88%)
- No: 2 votes (4%)
- I don't know: 4 votes (8%)

Question: What are the data gaps/what information is needed to make more informed decisions?
Summarized take-aways from poll responses and follow on discussion:
- Data gaps related to aerial mapping:
  - Long-term trend analysis of eelgrass coverage and density supported by aerial mapping
  - Accurate delineation of habitat boundaries
  - Need for data collection standards
  - Longer time horizons for analysis
  - Use of aerial imagery to assess recovery response rates
  - Subtidal and intertidal eelgrass mapping
- Topic areas and questions for future research:
  - Use of eDNA to analyze stomach contents of fish to assess diets
  - How to best match data collection methods with the key questions managers and researchers are trying to answer
  - How to best use aerial surveys for permitting of new aquaculture gear installations
  - How to best use spatial mapping coupled with other data analyses for permitting needs
  - How to best use sUAV for marine spatial planning efforts

APPENDIX A | Meeting Agenda

EELGRASS & AQUACULTURE | State of the Science Workshop

17 January 2024 | 10:00 am – 4:00 pm
Lacey Community Center
6729 Pacific Ave SE, Olympia, WA 98503

AGENDA

Time	Session	Presenter(s)
10:00 am	**Welcome, Housekeeping, Agenda Review**	▪ **Meagan Wylie**, Seatone
10:10 am	**Project Overview + Purpose of Workshop**	▪ **Bobbi Hudson**, Pacific Shellfish Institute
10:30 am	**"Boots in the Mud" Field Work Reporting:** How Aquaculture Affects Eelgrass and Nekton [WA and OR Focused] ▪ Eelgrass response to intertidal stress and aquaculture ▪ Nekton community response to gradients of eelgrass and different oyster aquaculture methods ▪ Seasonality of nekton species use of intertidal estuarine habitats, and response to eelgrass and to ground and off-bottom culture ▪ Nekton response to flip-bags co-located with eelgrass ▪ Trophic level responses to different longline densities and clustering ▪ Eelgrass resilience to mechanical harvest	▪ **Jen Ruesink**, University of Washington ▪ **Kelly McDonald**, Confluence Environmental ▪ **Fiona Boardman**, University of Washington ▪ **Katie Houle**, Pacific Shellfish Institute ▪ **Maria Garcia**, University of Washington
11:45 am	**Group Discussion Session** ▪ Are there management implications of this work? ▪ What are the data gaps for this research area? ▪ What information is needed to make more informed decisions?	▪ **All Participants**
12:30 pm	**LUNCH BREAK!** Catered on site	

1:15 pm	**eDNA Complementarity with Other Observations of Fish in CA and WA Aquaculture, Eelgrass, and Mudflats**	▪ **Rachel Meyer,** UC Santa Cruz
1:30 pm	**Fish Diet Response to Eelgrass and Oyster Aquaculture** [OR and WA focused]	▪ **Jason Toft**, University of Washington
1:45 pm	**Shellfish Aquaculture Farms as Foraging Habitat for Nearshore Fishes and Crabs in Puget Sound**	▪ **Karl Veggerby**, Anchor QEA
2:00 pm	**BREAK** Coffee & Cookies	
2:10 pm	**Mapping Eelgrass with Aerial Imagery:** Methodology and Change Analysis for Eelgrass Density/Cover Across Estuaries and Oyster Beds ▪ Landscape-scale mapping of eelgrass and aquaculture: distributions, interactions, and historical comparisons. ▪ The best methods to map eelgrass and how to use drone imagery to supplement these methods and improve accuracy ▪ Describing changes to eelgrass cover and density from aquaculture activities at the farm scale	▪ **Brett Dumbauld**, United States Department of Agriculture ▪ **Nate Lewis**, Oregon State University ▪ **Phil Bloch**, Confluence Environmental Co. ▪ **Kelly McDonald**, Confluence Environmental
3:00 pm	**Economics:** Costs and Profitability of Different Gear Types for Ground and Off-bottom Oyster Aquaculture	▪ **Olivia Horwedel**, Pacific Shellfish Institute / University of Washington
3:15 pm	**Group Discussion Session** ▪ Can aerial mapping and analysis of eelgrass densities be useful in regulatory decision making? ▪ What, if any, are the management implications of this work? ▪ What are data gaps / what information is needed to make more informed decisions?	▪ **All Participants**
3:55 pm	**Next Steps & Closing**	▪ **Bobbi Hudson**
4:00 pm	**ADJOURN**	

APPENDIX B | Discussion Sessions & Polling Outputs

At two junctures during the workshop, participants were invited to engage in an informal polling exercise using *Slido* technology to provide feedback on several prompting questions related to the presentations. Participation was voluntary and anonymous.

Direct responses to the *Slido* prompting questions are provided below. Only minor modifications to select statements were made to improve readability and remove redundancies. Responses have been generally grouped by similarity of topic.

DISCUSSION SESSION #1

This polling exercise and group discussion session followed these presentations:

- *Eelgrass Trait Response to Intertidal Stress and Aquaculture*
- *Nekton Community Response to Gradients of Eelgrass and Different Oyster Aquaculture Methods*
- *Seasonality of Nekton Species Use of Intertidal Estuarine Habitats, and Response to Eelgrass and to Ground and Off-bottom Culture*
- *Nekton Response to Flip-Bags Co-located with Eelgrass*
- *Trophic Level Responses to Different Longline Densities and Clustering*
- *Eelgrass Resilience to Mechanical Harvest*

Question: Are there management implications of this work?
Response:

- Yes: 58 votes (84%)
- No: 2 votes (3%)
- I don't know: 9 votes (13%)

Question: What are data gaps for this research area?
All Responses:
Aquaculture Operations

- Measuring eelgrass primary productivity under a variety of cultivation techniques
- Finer scale understanding of actual oyster stocking density impacts on the surrounding ecosystem
- Long-term installation versus recent installation of aquaculture gear
- Expand culture types to include surface floating oyster culture
- Effects of float bag or floating oyster culture on eelgrass, community composition, etc.
- Harvest technique impacts to eelgrass
- Assessment of mechanical harvest (dredge design) and experience level of operators
- Disturbance types can be further explored
- Does orientation of off-bottom gear (to wind, current, etc.) impact eelgrass differently?

- How do shellfish harvest events affect the abundance and diversity of nekton and macrofauna?

Habitat and Species Interactions

- Functional role of habitat/structure
- Effects to adjacent habitats
- Habitat classification
- Sensitivity of fish assemblages between aquaculture and non-culture sites
- Indigenous aquaculture (sea gardens, fishponds, etc.) interactions with nekton, eelgrass, etc. and how that compares to the methods of aquaculture in this study (this is not necessarily a gap in these studies, but I would be curious to see more about this)
- Impacts of aquaculture in eelgrass on predation and foraging behavior of salmonids
- Whether salmonids use eelgrass edge habitat and interior of eelgrass beds in the same manner
- More observations of salmonids and the effects of aquaculture related infrastructure
- What are the implications of this work on ESA salmonids?
- Species interactions at higher tropic levels
- Species interactions and food web analysis

Invasives

- European green crab risks to eelgrass and aquaculture
- European green crab effect on native species and eelgrass
- Invasive eelgrass is not protected under EFH. It is an eco-engineer that has destroyed tens of thousands of natural habitat [acreage] across Washington whether shellfish cultivation exists or not. Does the work discussed differentiate between native and invasive eelgrass?

Management and Policy

- Development of a roadmap for managing aquaculture as part of a mosaic rather than a binary – present/absent approach
- Identification of active management techniques that can be used to assist recovery following disturbance
- Linking the data with policy. The data is good, but if we can't use it for permitting it is tough to see where we are going.
- Understanding how to provide flexibility with culture methods and still provide stability of the various ecosystem services
- Oyster plantings create a habitat that attracts native eelgrass to areas that were void of eelgrass. Eelgrass moves in and brings with it increased regulatory restrictions to farming operations. What data is being compiled to document this scenario? The question exists how credit should be given to creating eelgrass areas. Left unmanaged for aquaculture, eelgrass beds will likely disappear over time without the habitat created by the oyster cultivation activity.
- Is all eelgrass equally critical as habitat? Should all eelgrass be treated equally in regulation?

Climate Change and External Impacts

- Dynamics of seasonal variation considering climate change – more heat and warmer water, etc.
- Impacts of ocean acidification and warming, and other extreme events
- Perhaps the bigger issue with ESA species is warming oceans, overfishing and river/stream habitat degradation.
- Climate change, ecosystem and landscape perspectives are important to link to how management decisions are made (i.e., ESA and MSA provisions).

Expansion of Research

- Expanding research to include seaweed aquaculture
- Efficacy of targeted planting of more resistant or better recovering eelgrass varieties in areas with a failing population
- Interactions of geoduck farming and eelgrass habitat
- Are interactions between eelgrass and aquaculture dependent on tidal elevation/ how does tidal elevation affect these relationships?
- This research is primarily conducted during daylight tides. Winter eelgrass and oyster relationships can be studied.
- Research simplifies intertidal habitats to two types (mudflat and eelgrass) and compares oyster aquaculture to these two. This neglects other habitat types that oyster aquaculture might better mimic, i.e., cobble, native oyster beds, macroalgae, etc.
- Is there a type or measure of stress on eelgrass that improves density?
- Are nekton using habitat for forage, or are they 'present' in those habitats?
- How much eelgrass or shellfish is necessary to drive a response?

Question: What information is needed to make more informed decisions?
All Responses:
Aquaculture Operations

- Production of oysters when clustered
- Impacts of flip-bags protecting eelgrass during extreme heat events that could otherwise cause eelgrass mortality
- Repeated demonstration of least impactful or most beneficial growing/harvesting methods
- The likelihood/capacity for a farm to modify its techniques
- Assess different culture methods
- What are the noticeable differences in community composition between aisle widths of longlines in eelgrass?
- How do employees working in an oyster bed affect eelgrass? Does more frequent travel across a bed result in a larger impact?
- Fowling on gear: what are the tradeoffs between feeding and cleaning?
- Would implementing clustered oyster beds with larger spacing for eelgrass increase nekton over time?
- It may be helpful to have more detailed information about the locations, culture methods and harvest timing used in each geographic area

Management and Policy

- Thresholds for what constitutes significant amounts of eelgrass to inform policy
- Trend hypothesis on eelgrass abundance and management methods (i.e., where to prioritize eelgrass management)
- How to best create models for management when historical data is often lacking for creating baselines
- Information or data that is specific to certain types of aquaculture or that compares two or more practices so that specific management actions can be taken, or so that farming practices can be adjusted
- Target goal for eelgrass densities, e.g., how to define "healthy" eelgrass abundance levels
- What is the ultimate goal and how do we get there? How do we adaptively manage in a dynamic environment that is so influenced by human activity?
- What are the broad long-term goals? How much eelgrass do we want? How many oysters do we want? How many Dungeness crab do we want? Unifying landscape goals are needed.
- What are the most effective steps that shellfish growers can take to maintain or improve eelgrass habitat?
- How do we tie policy to reality? What happens when oysters are planted and eelgrass colonizes an area because the substrate is stabilized? Is it regulated as if grass was or wasn't there?
- If eelgrass and oyster beds are not functionally equivalent, then what are the functional differences? Does the difference preclude both being ESA?

Scientific Methodology

- Best practices according to different climates and landscapes at growing locations
- A better set of metrics for evaluating eelgrass ecosystem health by spatial extent (since eelgrass is patchy, cover is perhaps the easiest way to get a snapshot during the growing season)
- Identify best practices associated with planting and harvesting activities for reducing impact to eelgrass habitat.
- What results in the significant error bars associated with most of the data? Why is there a wide range of variability in results? Was not enough data collected to make more informed conclusions?

Eelgrass, Nekton, and Aquaculture Interactions

- Nighttime monitoring for fish
- Understanding of episodic responses of nekton to harvest events. Are these bonanza foraging opportunities? Do they attract predators?
- More detailed information about the differences in the composition of nekton and epifaunal assemblages between aquaculture, eelgrass, and mudflats.
- Nekton community structures of oyster beds, both native Olympia and non-native Pacific oyster beds to compare flip-bags to.
- An understanding of the trade-offs between shellfish aquaculture, mixed beds with eelgrass, mudflats, and subtidal areas. There are good ways to sustainably grow shellfish.

- Salmon use of these habitats. Assessment of abundance, productivity, behavior
- Impacts of aquaculture to benthic invertebrate species diversity and abundance

Research Questions & Other

- Naturally occurring eelgrass density changes due to normal environmental cycles
- Long-term effects of warming ocean and competition with ESA species
- What is the natural baseline of eelgrass regarding spatial distribution and density?
- More landscape scale assessments of impacts of aquaculture on eelgrass, like what was done with aerial mapping in Willapa Bay. While we are not considering burrowing shrimp today, a landscape scale assessment of their reduction of eelgrass would also be valuable.
- Green crab effects on eelgrass and shellfish growing
- Are there species which provide a pseudo response to eelgrass health and presence?
- Are species present due to structural refuge from currents, or flow, or predator refuge, or for foraging opportunities?
- What provides similar environmental benefit for areas where eelgrass is absent?
- How does aquaculture disturbance compare to what can be expected without aquaculture?
- Longitudinal studies
- Traditional Ecological Knowledge (TEK)
- Epibenthos

DISCUSSION SESSION #2

This polling exercise and group discussion session followed these presentations:

- *eDNA Complementarity with Other Observations of Fish in California and Washington Aquaculture, Eelgrass, and Mudflats*
- *Fish Diet Response to Eelgrass and Oyster Aquaculture*
- *Shellfish Aquaculture Farms as Foraging Habitat for Nearshore Fishes and Crabs in Puget Sound*
- *Landscape-scale Mapping of Eelgrass and Aquaculture: Distributions, Interactions, and Historical Comparisons*
- *The Best Methods to Map Eelgrass and How to Use Drone Imagery to Supplement These Methods and Improve Accuracy*
- *Describing Changes to Eelgrass Cover and Density from Aquaculture Activities at the Farm Scale*
- *Economics: Costs and Profitability of Different Gear Types for Ground and Off-bottom Oyster Aquaculture*

Question: Can aerial mapping and analysis of eelgrass densities be useful in regulatory decision making?

Response:

- Yes: 45 votes (88%)
- No: 2 votes (4%)
- I don't know: 4 votes (8%)

Question: What are the data gaps/what information is needed to make more informed decisions?

All Responses:

<u>*Aerial Imagery and Mapping*</u>

- Types of permits needed to fly drones
- Use of aerial imagery for marine spatial planning
- Ability to broadly map aquaculture farm areas and eelgrass and other habitat types over bay scale areas
- Bay-wide imagery every 5 to 10 years via USDA
- Applications of artificial intelligence (AI) to decrease costs and time of mapping
- Standardization across mapping techniques
- Uniform process and standards for mapping eelgrass
- There is a need to refine drone eelgrass surveys to be able to distinguish *Zostera marina* from *Zostera japonica*
- Replication of aerial mapping efforts so that we can eventually parse out trends
- Creation of a centralized repository to help users understand what mapping data has been collected so people can 'discover' data that may not be publicly distributed
- Use of aerial imagery to document sediment accumulation from upland landscape usage like forestry practices and where fine sediments accumulate
- Currently we use remote mapping in a binary way – is it present or absent? In the future perhaps we will be able to map eelgrass ecosystem health, and site aquaculture in a way that enhances overall ecosystem health and function

<u>*Management and Policy*</u>

- Ability to adapt long-term permits to changing conditions
- Existing permit mapping is based on a snapshot on time. Longer term monitoring may help refine characterization of eelgrass as 'permanent' versus 'ephemeral' versus 'frequent' based on frequency of presence over time
- Interested parties' ability to access aerial mapping; perceptions of parties and the public of aerial mapping versus in water surveys for decision making

<u>*Aquaculture Operations*</u>

- A better understanding of farming methods that may promote eelgrass growth, and/or how different gear may help or hinder during heat dome events
- Research on alternative gear types to replace poly ropes
- Targeted harvest times for important species

<u>*Habitat and Species Interactions*</u>

- Forage fish use in eelgrass and shellfish beds
- What forage quality is readily available to be used by nearshore dependent juvenile salmonids. Compare eelgrass and mudflat with different aquaculture growing techniques
- All research presented was looking at mud flats, sparse eelgrass beds, dense eelgrass beds, no aquaculture, aquaculture (oysters). Why was no research done on natural shellfish beds (for example the oyster reserve in Willapa Bay to name one area)? What species are living, eating, thriving in these natural beds, is eelgrass

intermixed, at what density, how similar/different are these natural beds compared to aquaculture?

- It is unclear if habitat relationships are meaningful since it is unclear how 'close' an organism needs to be to be detected.

Invasives

- Characterization of temporal and spatial variability in the extent, density, dynamics of burrowing shrimp beds in tideflat habitats
- It would be helpful if the Willapa aerial surveys could document the acres of eelgrass being lost by the expansion of burrowing shrimp that growers and others are observing anecdotally

Research Methods and Other

- Consistent standards for how data are collected and processed
- An easy way for industry to contract with qualified teams to collect these data is needed
- Elevation data around eelgrass areas to better plan for sea level rise
- Year-to-year characterization of variability in eelgrass metrics (above ground and below ground)
- Collect index eDNA information to better resolve broad scale patterns of species use by geography and timing
- Increased analyses following extreme events and subsequent recovery across different landscapes and environmental conditions
- Correlation data between ecosystem changes as they impact eelgrass areas
- Ability to gather information from subtidal surveys
- Landscape scale co-variates
- We need context for the change. Correlation and causation are not always the same
- Recovery response and understanding habitat mosaics are important to maintain based on species use/prey needs
- What about sub tidal eelgrass? Is it less important than intertidal eelgrass?

APPENDIX C | Participant List

First name	Last name	Affiliation
In Person Participants		
Aimee	Christy	Pacific Shellfish Institute
Amanda	Carr	Plauche & Carr LLP
Andy	Suhrbier	Pacific Shellfish Institute
Anna	Wallace	Washington State Department of Ecology
Annie	Raymond	Jamestown S'Klallam Tribe
Ashleigh	Epps	Washington Sea Grant
Aspen	Katla	University of Washington, Ruesink Lab
Beth	Sanderson	NOAA Fisheries
Bill	Dewey	Taylor Shellfish Farms
Blair	Paul	Skokomish Tribe
Bob	Oxborrow	UW School of Aquatic and Fisheries Science
Bobbi	Hudson	Pacific Shellfish Institute
Brett	Dumbauld	USDA - Agriculture Research Service
Brian	Sheldon	Northern Oyster Company
Bridget	Moran	Skagit River System Cooperative
Catalina	Burch	The Nature Conservancy, Washington Sea Grant
Cynthia	Harbison	Washington Department of Natural Resources
Derek	Epps	Geoduck LLC
Dan	Cheney	Pacific Shellfish Institute
Emma	Saas	Port Gamble S'Klallam Tribe
Erin	Ewald	Taylor Shellfish
Fiona	Boardman	University of Washington
Frithiof	Waterstrat	United States Fish and Wildlife Service
Gary	Fleener	Hog Island Oyster Company
Hannah	King	Washington Department of Natural Resources
Jason	Haveman	Port Gamble S'Klallam Tribe
Jason	Ragan	Taylor Shellfish
Jeb	Sheldon	Northern Oyster Company
Jennifer	Ruesink	University of Washington
Julia	Kobelt	University of Washington
Kalloway	Page	Pacific Shellfish Institute
Karl	Veggerby	Anchor QEA
Katie	Houle	Pacific Shellfish Institute
Katie	Allen	Washington Department of Natural Resources
Kelly	McDonald	Confluence Environmental Company
Kyle	Deerkop	Pacific Seafood
Kyra	Anderson	Washington Department of Natural Resources

Laura	Spencer	Pacific Shellfish Institute
Laura	Butler	Washington State Department of Agriculture
Liz	Tobin	Jamestown S'Klallam Tribe
Lizzie	Carp	Washington State Department of Ecology
Margaret	Homerdinger	Nisqually Tribe
Maria	Garcia	University of Washington
Maria	Pazandak	Contractor with National Marines Fisheries Service
Marilyn	Sheldon	Northern Oyster Company
Marlene	Meaders	Confluence Environmental Company
Mary	Monahan	Washington Department of Natural Resources
Mary Elizabeth	Bissell	Pacific Shellfish Institute
Max	Showalter	Washington Department of Natural Resources
Meagan	Wylie	Seatone Consulting
Micah	Horwith	Washington State Department of Ecology
Nate	Lewis	Oregon State University - US Department of Agriculture
Nyle	Taylor	Taylor Shellfish Farms
Olivia	Horwedel	Pacific Shellfish Institute and University of Washington
Phil	Bloch	Confluence Environmental Company
Rachel	Skubel	Washington Dept of Natural Resources, Aquatics
Rachel	Meyer	University of California Santa Cruz
Rebecca	Cohen	Taylor Shellfish
Rich	Doenges	Washington Department of Ecology
Rich	Wilson	Seatone Consulting
Sandy	Zeiner	Northwest Indian Fisheries Commission
Sarah	Anderson	The Suquamish Tribe
Scott	Mazzone	Quinault Indian Nation
Scott	Steltzner	Squaxin Island Tribe
Shannon	Boldt	Pacific Shellfish Institute
Shannon	Miller	Point No Point Treaty Council
Stephanie	Ehinger	National Oceanic and Atmospheric Administration
Steve	Booth	Pacific Shellfish Institute
Suzie	O'Neill	NOAA Fisheries
Teressa	Pucylowski	Washington Department of Ecology
Will	Moseley	Washington Department of Ecology
Yvonne	Shevalier	Interested Citizen
Webinar Participants		
Amanda	Canepa	*Affiliation unknown*
Arn	Aarreberg	California Department of Fish and Wildlife
Brian	Katz	Cascadia Visualizations LLC and Oregon State University
Brooke	McIntyre	United States Department of Agriculture
Caitlin	Magel	University of Washington

Catey	Ritchie	*Affiliation unknown*
Chris	Schillaci	National Oceanic and Atmospheric Administration
Corianna	Flannery	California Department of Fish and Wildlife
David	Beugli	Willapa Grays Harbor Oyster Growers Association
Franchesca	Perez	Stillaguamish Tribe of Indians
Heidi	Stewart	*Affiliation unknown*
Janice	Martin	Quinault Indian Nation
Jess	Pyle	Washington Department of Fish and Wildlife
Julia	McDowell	*Affiliation unknown*
Julie	Rose	NOAA Fisheries Milford Laboratory
Kat	Garrah	Drayton Harbor Oyster Co.
Kathleen	Moncy	Goose Point Oyster
Laura	Gray	NOAA National Marine Fisheries Service
Leslie	Hart	California Department of Fish and Wildlife
Lucas	Rabins	*Affiliation unknown*
Mary	Cockrell	National Oceanic and Atmospheric Administration
Melissa	Ward	Oregon State University
Mike	McHugh	Tulalip Tribe
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Sara	Azat	NOAA Fisheries
Sarah	Albright	United States Army Corps of Engineers
Stephen	Phillips	Pacific States Marine Fisheries Commission
Steven	Rumrill	Oregon Department of Fish and Wildlife
Steve	Seymour	Drayton Harbor Oyster Co.
Suzanne	Shull	Padilla Bay National Estuarine Research Reserve
Sylvia	Yang	Padilla Bay Reserve
Teri	King	NOAA Fisheries
Tori	Cantelow	Point No Point Treaty Council
William	House	Washington Department of Natural Resources

Eelgrass & Aquaculture | State of the Science Workshop

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Bobbi Hudson is Director of the Pacific Shellfish Institute (PSI) and serves on various committees related to marine water quality and ecology, shellfish production, and the International Council for the Exploration of the Sea (ICES) Expert Working Group on Ecological Carrying Capacity in Aquaculture. She holds B.S. and M.S. degrees in Environmental Science from The Evergreen State College. Bobbi splits her time between Olympia, WA, SE Alaska, and Vancouver Island, BC.

BRETT DUMBAULD | United States Department of Agriculture

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Landscape-Scale Mapping of Eelgrass and Aquaculture: Distributions, Interactions, and Historical Comparisons | Dr. Brett Dumbauld is a Research Ecologist with USDA-ARS at the Hatfield Marine Science Center in Newport, Oregon. His research focuses on developing a better understanding of the ecology of bivalve shellfish aquaculture in US West Coast estuaries. |
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Seasonality of Nekton Species Use of Intertidal Estuarine Habitats, and Response to Eelgrass to Ground and Off-Bottom Culture *and* **Eelgrass Resilience to Mechanical Harvest** | Fiona Boardman is a fourth year PhD candidate in the Ruesink Lab. Her work examines the effects of oyster aquaculture on intertidal communities, including seagrass, shorebirds, fish, and invertebrates. |
Acknowledgements: Taylor Shellfish

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Fish Diet Response to Eelgrass and Oyster Aquaculture | Jason Toft is a principal research scientist at the University of Washington School of Aquatic and Fishery Sciences in the Wetland Ecosystem Team. The ecological interactions of juvenile fish and invertebrates with estuarine systems is the underlying framework for most of his research. | **Collaborators & Acknowledgements:** Jeff Cordell, Julia Kobelt, Bob Oxborrow, Alyssa Suzumura, Arielle Tonus Ellis, Katie Houle, Fiona Boardman, Jennifer Ruesink, Brooke McIntyre, Brett R Dumbauld

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Eelgrass Response to Intertidal Stress and Aquaculture | Jennifer Ruesink is a professor of Biology at the University of Washington, whose research focuses on mudflat ecology and the roles of native and non-native species as ecosystem engineers. She has published >100 peer-reviewed papers over 2 decades and strives for co-production of research with shellfish growers and agency scientists. | **Collaborators & Acknowledgements:** Shellfish companies - Jolly Roger, Northern Oyster, Pacific, Taylor, R&B, Goose Point, Heckes. Research techs - Elena Subbotin, Chris Jendrey, Haleh Mawson, Sunny Kemmer, James Fitzpatrick

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Shellfish Aquaculture Farms as Foraging Habitat for Nearshore Fishes and Crabs in Puget Sound | Karl is a fisheries biologist at Anchor QEA with more than 9 years of experience conducting research across the Pacific Northwest. He has a master's degree in aquatic and fishery sciences from the University of Washington. He previously worked as a contract fisheries biologist at the National Oceanic and Atmospheric Administration's (NOAA's) Northwest Fisheries Science Center where he led biannual field expeditions to the Salmon River as part of a long-term stream survey project. He also worked on a wide variety of research projects across the Columbia River and western Washington, with experience in both freshwater and marine environments throughout Puget Sound and the Pacific Northwest. | **Collaborators:** Collaborators: Mark D. Scheuerell, Beth L. Sanderson, Peter M. Kiffney | **Acknowledgements:** This research was conducted in collaboration with support of shellfish aquaculture farms and Padilla Bay National Estuarine Reserve in Washington, USA. The study was funded by the NOAA Office of Aquaculture and Borman Research Grant.

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Nekton Response to Flip Bags Co-Located With Eelgrass, Including Fish Behavior and Abundance | Katie Houle is a Senior Biologist at PSI. Katie led the PSI team in data collection on Washington state shellfish farms and coordinated research activities among consortia scientists. She studies aquaculture/environment interactions, shellfish biology and estuarine ecology. | **Acknowledgements:** The team at PSI: Andrew Suhrbier, Kalloway Page, Aimee Christy, Evie Fagergren, Shannon Boldt, Terence Lee, Isabel Platten, Natalie Sahli, Mary Middleton

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Nekton Community Response to Gradients of Eelgrass and Different Oyster Aquaculture Methods *and* Mapping Eelgrass with Aerial Imagery | Kelly is a marine ecologist specializing in interactions between shellfish aquaculture and regulated resources (e.g., eelgrass, listed species). In her work, she regularly conducts drone-based surveys to inform resource management and supports shellfish growers through the federal, state, and local permitting processes. | **Collaborators and Acknowledgements:** Jennifer Ruesink (UW), Fiona Boardman (UW), Katie Houle (PSI), Bobbi Hudson (PSI), Phil Bloch (Confluence), and all who helped collect and process the seine samples!

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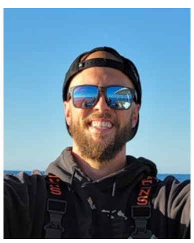
Trophic Level Responses to Different Longline Densities and Clustering | Maria is a first yeah PhD student working in the Ruesink lab at the University of Washington. She is interested in thinking about how changes in foundation species, like eelgrass, affect higher trophic levels.



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Landscape-Scale Mapping of Eelgrass and Aquaculture: Distributions, Interactions, and Historical Comparisons | Nate is an OSU faculty research assistant in the Dumbauld Ecology Lab. His primary research focus is geospatial and geostatistical modeling of estuarine shellfish and their habitats. | **Collaborators:** Brett Dumbauld, Brooke McIntyre, Jennifer Ruesink, Fiona Boardman, David Beugli | **Acknowledgements:** OSU - Joe Brockman, Austin Williams, Annie Merrill; UW - Alan Trimble, Chris Jendrey, Haleh Mawson, Wesley Hull, Florencia Visconti, Katie Ruesink; WGHOGA - Taylor Shellfish, Pacific Seafoods, R&B Oyster Co., Northern Oyster Co., Jolly Roger Oyster Co., Goose Point Oyster, Chetlo Harbor Shellfish

OLIVIA HORWEDEL | Pacific Shellfish Institute & University of Washington
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Economics: Costs and Profitability of Different Gear Types for Ground and Off-bottom Oyster Aquaculture | Olivia Horwedel is a PhD student at the University of Washington where she finished her Masters of Marine Affairs in Spring 2023. During her masters, she worked with Pacific Shellfish Institute as a research intern where she worked on publishing two reports with Dr. Trina Wellman focusing on aquaculture profitability and shellfish aquaculture ecosystem services. Her current research expands from shellfish to look at the intersections between marine conservation and coastal Indigenous food systems through a Two-Eyed Seeing approach. | **Collaborators & Acknowledgements**: I would like to thank Dr. Trina Wellman for her mentorship during this project and assistance in creating the reports. I would also like to thank Bobbi Hudson for her support and edits during this process.

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The Best Methods to Map Eelgrass and How to Use Drone Imagery to Supplement These Methods and Improve Accuracy *and* Describing Changes to Eelgrass Cover and Density From Aquaculture Activities at the Farm Scale | Phil has more than 20 years of experience mapping and managing intertidal ecological systems for the purpose of conserving sensitive resources while supporting the multiple uses of intertidal and marine areas. He communicates and translates scientific information so that managers and citizens can use the information to make important decisions. | **Collaborators and Acknowledgements:** Jennifer Ruesink (UW), Taylor Shellfish (Bill Taylor, Erin Ewald, Nyle Taylor, Elijah Parson, Jason Ragan), PSI (Bobbi Hudson and Katie Houle), Whelan Gilkerson (Merkel & Associates), Pacific Seafoods

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eDNA Complementarity with Other Observations of Fish in CA and WA Aquaculture, Eelgrass, and Mudflats | Rachel Meyer is the director of the CALeDNA community science program and an adjunct assistant professor in Ecology and Evolutionary Biology at the University of California Santa Cruz where she teaches molecular ecology and leads research projects on plant population genomics, paleogenomics, and ethnobotany. She also runs trainings in bioethics and science policy around digital sequence data and broadening genomics capacity in developing countries. | **Collaborators:** Sean Johnson, Kristy Kroeker, Jennifer Ruesink, Katie Houle, Fiona Boardman, Brett Dumbauld, Beth Sanderson, Bobbi Hudson, Kelly McDonald, Phil Bloch, Brooke McIntyre, Jason Toft, Jeff Cordell | **Acknowledgements:** Jen Quick-Cleveland, Ariel Levi Simons, Eric Palkovacs, Hector Baez, Lenore Pipes, Julie Stanford