AGRICULTURAL RESEARCH FOUNDATION
FINAL REPORT
FUNDING CYCLE 2016 – 2018

TITLE: Relationships of shellfish culture and seagrass habitats in Oregon Estuaries: quantification of impacts and functional roles for regulatory purposes

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EXECUTIVE SUMMARY: The U.S. is one of the largest importers of seafood in the world, with approximately 91% of the fish and shellfish consumed being supplied by other nations. These imports account for ca. $15.7 billion, half of which originates from aquaculture (NOAA 2012). Increasing domestic production of molluscan shellfish through commercial aquaculture operations is one promising approach to reduce this deficit. An unfilled domestic and overseas demand for oysters exceeds current domestic supply, and there is renewed interest in expanding the industry (NOAA 2011). The shellfish aquaculture industry however, is currently constrained by several problems including environmental regulations concerning the impact of shellfish farming practices on the estuarine environment. The known role of seagrass (primarily *Zostera marina* on the U.S. west coast) as estuarine nursery habitat, as well as no-net-loss provisions in federal and state regulations has resulted in a precautionary approach by managers that avoids any direct impacts to seagrass altogether, therefore directly impacting shellfish growing activities. Eelgrass (*Zostera marina*) is designated as Essential Fish Habitat (EFH) for federally managed fish species within the Pacific Coast Groundfish and the Pacific Coast Salmon Fisheries Management Plans (Pacific Fishery Management Council 2008), and as habitat area of particular concern (HAPC) for species within the Pacific Coast Groundfish Fisheries Management Plan. Yet, knowledge of impacts of molluscan shellfish on seagrass and estuarine ecosystem services is very limited (e.g. Dumbauld et al. 2009). Consequently, there is an urgent need for a good understanding of the influence of aquaculture on estuarine habitats and development of environmentally and economically sustainable shellfish farming practices to sustain and expand the industry. However, little scientific guidance exists for managers regarding the actual activities that would endanger the functional value of this habitat for other species, and how to quantify those impacts. The proposed research will fill key information gaps, distinguishing between actual and perceived environmental effects of shellfish aquaculture on estuarine functioning.

OBJECTIVES:

1) Measure the effect of shellfish culture on seagrass
2) Quantify the function of shellfish culture and seagrass as habitat for fish and invertebrates.

PROCEDURES:

For objective 1, we will examine the direct effects of shellfish culture on seagrass, primarily by monitoring seagrass health status (seagrass abundance and growth) with respect to the type and density of shellfish culture, keeping other environmental variables such as tidal elevation as consistent as possible. These measurements will be conducted along transects from shellfish farms to distances of up to 30 m away from farms.

Regarding objective 2, we will examine the functional value of these habitats by quantifying fish and invertebrate use utilizing underwater video, direct visual surveys with snorkel observations, and pump samples of bottom-associated invertebrates. Target species will include Dungeness crab, juvenile English sole, and juvenile salmon, but also include small invertebrates (e.g. snails, crustaceans) that are prey for these species.

While we had originally proposed to work in Coos Bay, after approval from Dr. Karrow, we switched our sampling efforts to another Oregon estuary: Tillamook Bay, because there are no longline aquaculture facilities in Coos Bay (while they are present in Tillamook). The main reason for being interested in longline aquaculture, is that it will allow us to compare our results with those obtained in other estuaries along the Pacific Northwest (work being conducted through another project funded by the NOAA Saltonstall Kennedy program; reference NOAA-NMFS-FHQ-2015-2004246, as mentioned in the original proposal) and thus will put our results in a wider context and allow us to use the data obtained in the other estuaries to obtain a broader and better understanding of the processes regulating the interaction between eelgrass beds and aquaculture.

SIGNIFICANT ACCOMPLISHMENTS:

Work completed during this reporting period has focused primarily on performing sampling, processing samples, and analyzing data for Objectives 1 and 2. Joint in-person and conference call meetings were held between team members at several times during this reporting period. Remaining sample analyses and data analyses for those objectives will be completed in the next months (a no cost extension was approved by Dr. Karow on April 27th 2017). The following is a summary of the principal activities performed and results obtained during this reporting period.

Measurement and quantification of the effects of shellfish culture on seagrass and its function as habitat for fish and invertebrates.

We examined Tillamook Bay, an estuary containing a mix of oyster culture and seagrass habitats. Research components addressed: 1) measurement of seagrass abundance across shellfish/seagrass boundaries; 2) quantification of fish and invertebrates using minnow traps and underwater video; 3) determination of abundance and taxa of epibenthic invertebrates at one site; and 4) tethering experiments to assess predation. Sampling design differed slightly between 2016 and 2017. While in 2016 we performed a 50m transect (Figure 1) in each habitat type (eelgrass, edge, culture bed) at each site, in 2017 a single transect was placed across and perpendicular to the edge of the shellfish bed from approximately 30 m outside the bed in eelgrass habitat to 30 m within the bed (Figure 2) and this was performed at three sites.

Measurement of seagrass abundance

In 2016, measurements were made at 20 random points along a 50m transect (Figure 1) in each habitat type (eelgrass, edge, culture bed) at each site. *Zostera marina* density was assessed by counting shoots within a 625cm^2 quadrat placed on alternate sides of the transect line at the 20 random points. Percent cover of macroalgae (eg. *Ulva*), inundation of water, and percent cover of epiphytes on blades was also measured and recorded. One shoot was haphazardly collected from each quadrat and placed into a gallon bag for later analysis of biomass. A similar procedure was used in 2017, where eelgrass data were collected every 3 m along the transect, resulting in a total of 21 data points at each site. At each point, a 0.0625m^2 quadrat was used to assess percent cover of the native eelgrass (*Z. marina*) and macroalgae, in addition to the percent cover of epiphytes on the eelgrass blades within the quadrat. The number of eelgrass shoots was also counted. To further characterize the habitat structure, 10 eelgrass shoots were collected from each of the five main points along the transect.

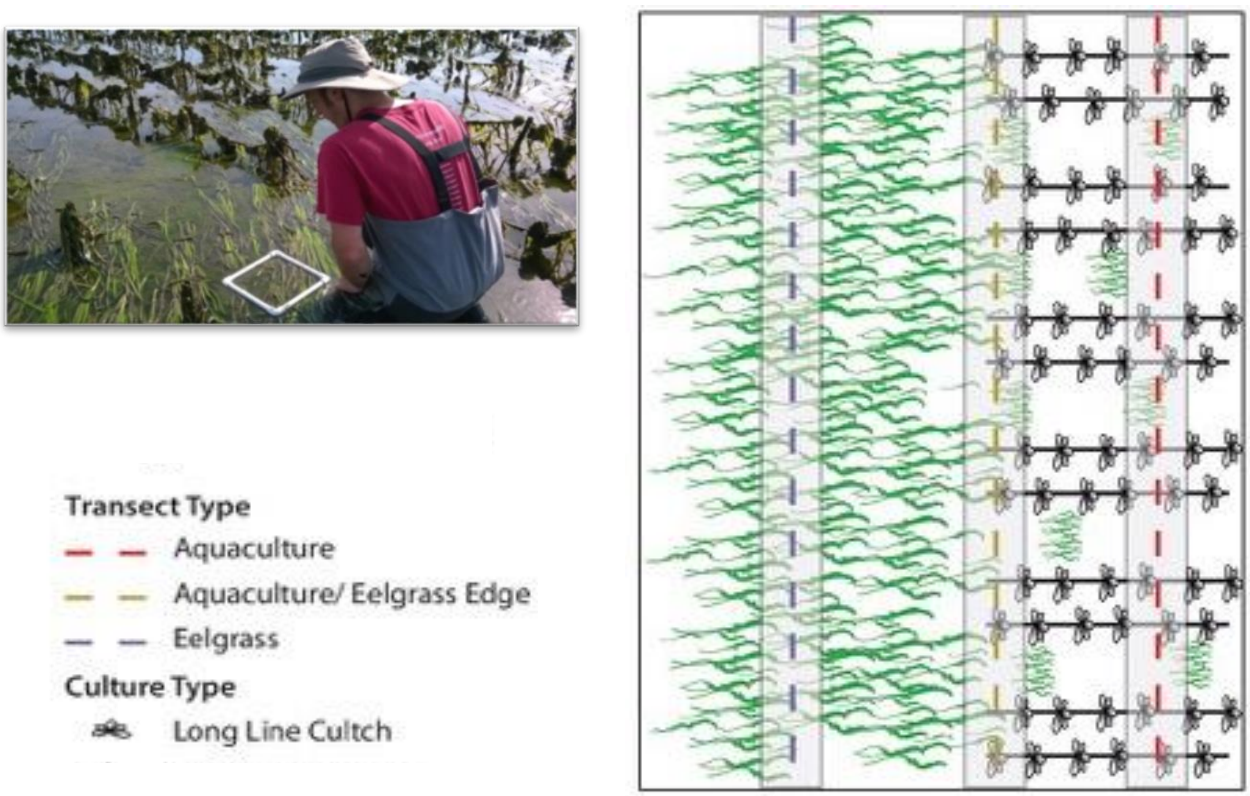


Figure 1. A 50m transect line was used in each habitat type (blue- eelgrass, yellow-edge, and red- longlines). Although consistent layouts were attempted, several sites required transect lines to be perpendicular to the longlines.

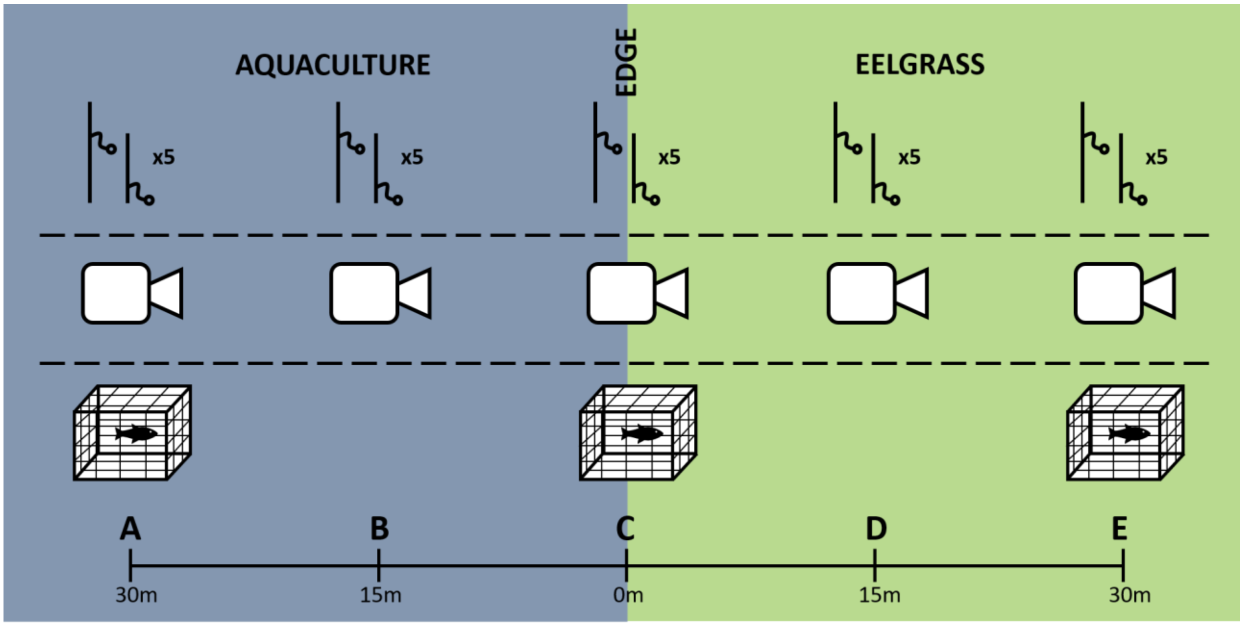


Figure 2. Sampling design performed during 2017. A 60m transect was laid perpendicular to the boundary between the aquaculture and eelgrass habitats. At each of five, evenly-spaced points (15m apart) along the transect (A-E), an array of sampling methods was used to characterize the differences in species presence and behavior. These five points were considered to represent different regions within the habitat matrix: A) aquaculture interior, B) aquaculture intermediate, C) edge, D) eelgrass intermediate, and E) eelgrass interior. The edge was always placed in the middle of the transect, so the interior habitats were each 30m into the respective habitat.

In the laboratory, the longest blade of the collected shoot was measured for height and width and then scraped with the side of a microscope slide to remove all epiphyte cover from the blade. The scraped epiphyte material was placed into a pre-weighed baking tin and dried in an oven at 60 degrees C for 48 hours or until a constant weight was achieved. The shoots were placed into a foil pouch and dried at 60 degrees C for 48 hours. The samples were then weighed and biomass was calculated for each sample. These measurements can be extrapolated to the entire transect area using the shoot density counts taken in the field. Growth measurements were not taken in the 2016 nor 2017 field season due to logistical challenges. Eelgrass shoot samples for 2016 have been processed at OSU; samples for 2017 need to be processed.

Seagrass abundance data suggests that there is an effect (negative) of aquaculture on eelgrass abundance, with higher shoot density found in eelgrass habitat and the edge, and lower seagrass abundance inside the aquaculture area (Figure 3).

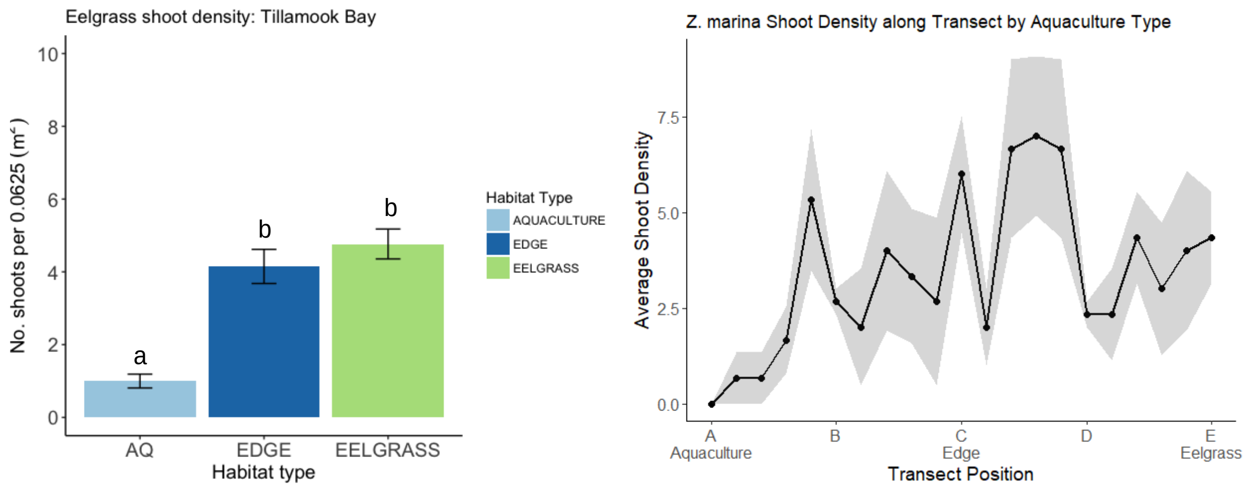


Figure 3. Mean (+ 1 SE) *Zostera marina* shoot density by habitat type in Tillamook Bay measured in 2016 (left) and 2017 (right). Lower case letters on the 2016 figure designate statistically significant differences amongst groups (Tukey test).

In accordance with density data, eelgrass biomass (g DW) was also lowest in the aquaculture habitat. Indeed, not only are plants less abundant in aquaculture, but they are also smaller plants (Figure 4). Conversely, epiphyte load (i.e. biomass of epiphytes relative to biomass of plant) is higher on seagrass from the aquaculture and edge habitats (Figure 5). Epiphytes can outcompete seagrass for light and cause seagrass decline (Hughes et al. 2004), and could be a potential cause of lower seagrass abundance in the aquaculture habitat.

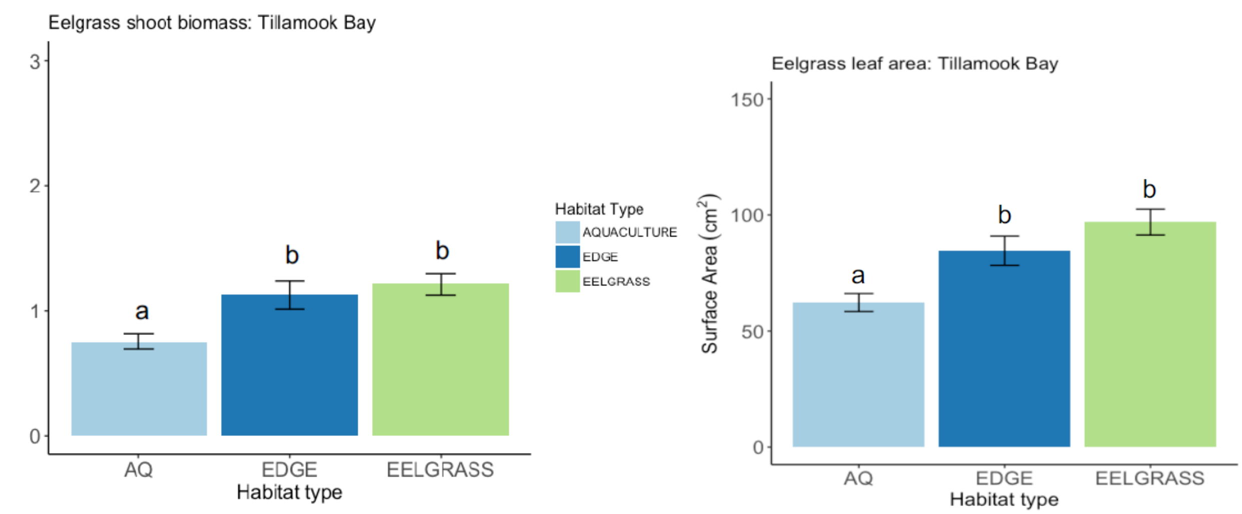


Figure 4. Mean (+ 1 SE) *Zostera marina* shoot biomass (left) and surface area (right) in from plants collected in Tillamook Bay in 2016. Lower case letters designate statistically significant differences amongst groups (Tukey test).

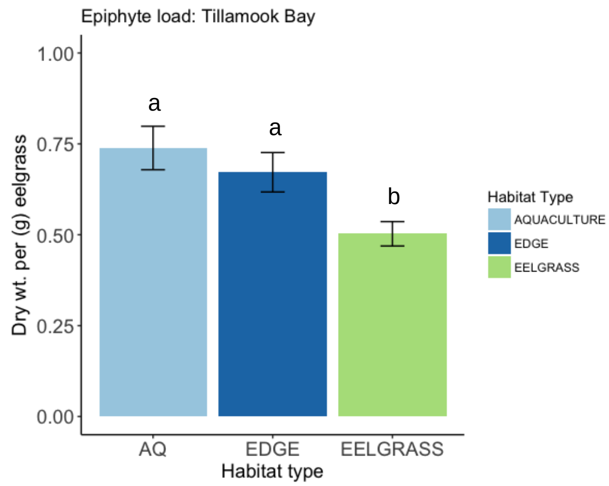


Figure 5. Mean (+ 1 SE) Epiphyte load on *Zostera marina* plants collected in Tillamook Bay in 2016. Lower case letters designate statistically significant differences amongst groups (Tukey test).

Epibenthic sampling

The three habitats described above—eelgrass, edge, and oyster line culture—were sampled for epibenthic invertebrates on a single tide at one site in Tillamook Bay in 2016. Either 7 or 10 replicate samples (number determined by the time window allowed by incoming tides) were taken at each habitat. Epibenthic invertebrates were collected by wading using a 2000-gallon hour^{-1} 12-volt electric bilge pump, housed at the top of a 14.8 cm wide PVC sampling cylinder, open only at the base (Figure 6), which sampled the water ~25 cm above the bottom and encompassed an area of 0.018 m^2 of the benthic substrate. The sampling cylinder was equipped with 0.106 µm mesh screening over replacement water ports, allowing a quantitative sample of the enclosed epibenthos to be obtained without external contamination. For each sample, the cylinder was gently placed on the sediment surface, and water was pumped for 20 seconds, or until benthic sediments were noticed in the pump's clear plastic outflow hose. Material from the pump was collected on a 0.106 µm sieve and the filtrate was fixed in a 5% buffered formaldehyde solution. In the laboratory, invertebrates were identified to the species level for most adult crustaceans (e.g., gammarid amphipods, tanaids, harpacticoid copepods) and to family or higher taxonomic category for other groups. Strictly planktonic (e.g., most calanoid copepods) or benthic (e.g., nematodes) were not targeted by the sampling methodology, and were not enumerated.

Figure 6. Epibenthic sampling pump (left) and sampling team.

Multivariate data describing the epibenthic community was standardized prior to analysis. Species that occurred in less than 3% of samples were excluded, and abundances were log-transformed. Patterns in community composition were visualized by nonmetric multidimensional scaling (NMDS). Permutational multivariate analysis of variance (PERMANOVA) was used to test for differences in the overall assemblage compositions. Multivariate tests used the Bray-Curtis similarity, with an unrestricted permutation of the raw data which is recommended for small sample sizes and single-factor tests. P-values <0.05 were considered statistically significant when making comparisons among the three strata. Comparisons of log-transformed densities and taxa richness among the three sampling strata were also analyzed using one-way ANOVA. We then used post-hoc Tukey tests to compare means between pairs of variables when the initial ANOVA showed significant results.

Harpacticoid copepods dominated all habitats (Figures 7,8). There was a pattern of decreasing overall abundance from eelgrass to edge to oyster culture for both total invertebrates and harpacticoid copepods. However, these among-habitats differences were not statistically significant for total invertebrates (Table 1). Some taxa were relatively abundant in eelgrass and edge, but largely absent or reduced in oyster culture strata (e.g., *Mesochra pygmaea, Ameira longipes*) while others were more evenly distributed among the habitats (e.g., *Leima vaga*, *Tisbe* spp.).

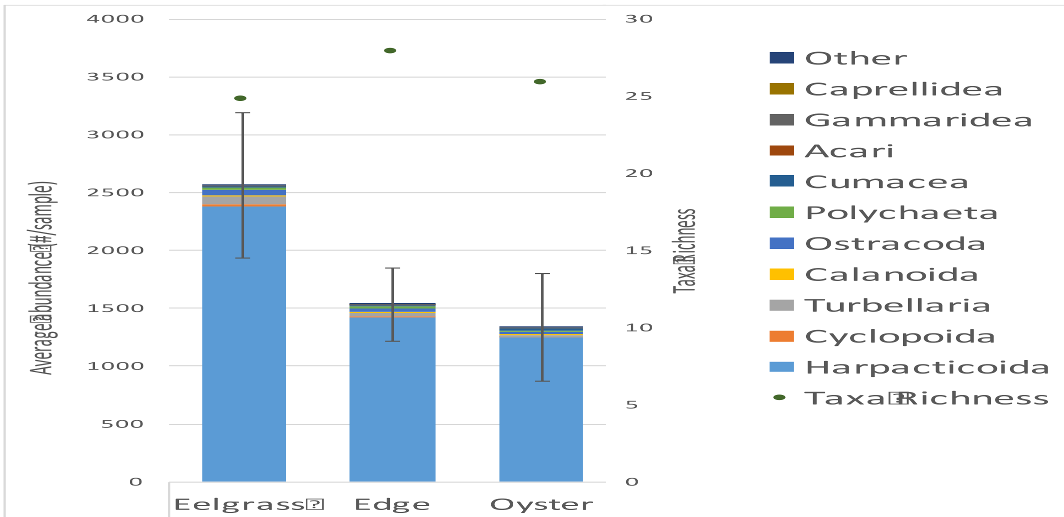


Figure 7. Abundances of major groups of epibenthic organisms at the different habitats in Tillamook sampled in 2017.

PERMANOVA results indicate that assemblages among the three habitats are significantly different (Table 1). These differences are also evident in the NMDS plots in which the three habitats cluster separately (Figure 9). Several taxa were particularly indicative of the eelgrass habitat, including the calanoid copeod *Eurytemora americana* and the harpacticoid copepods *Mesochra pygmaea* and *Ameira longipes*. The oyster culture habitat was associated with a suite of harpacticoid copepods plus the cumacean *Cumella vulgaris*.

Table 1. Statistical results from epibenthic pump samples**.**

	Habitat	post-hoc
Taxa richness	0.256	
Total	0.094	
Harpacticoid	0.103	
Assemblage (Permanova)	**0.0001**	All habitats different

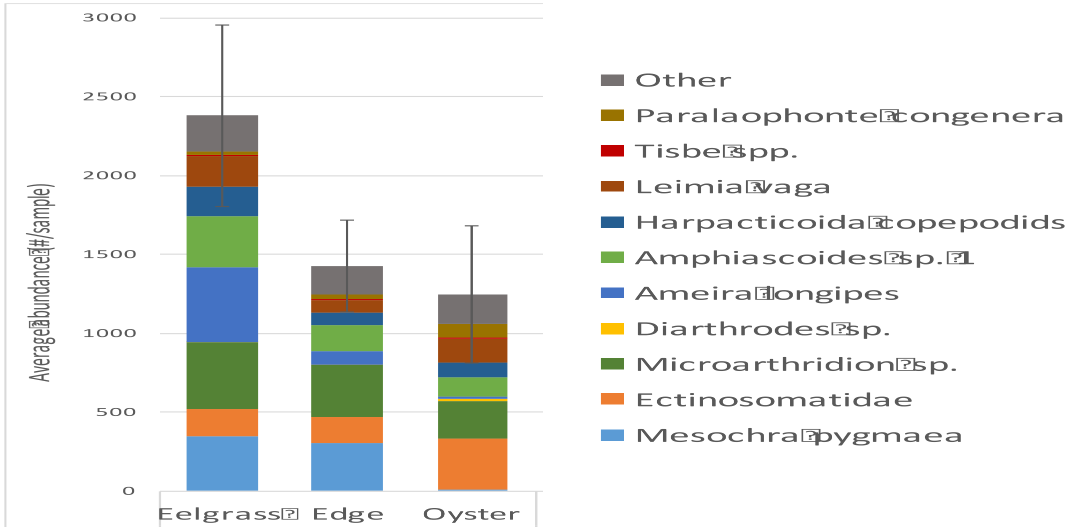


Figure 8. Abundances of harpacticoid copepods at the different habitats.

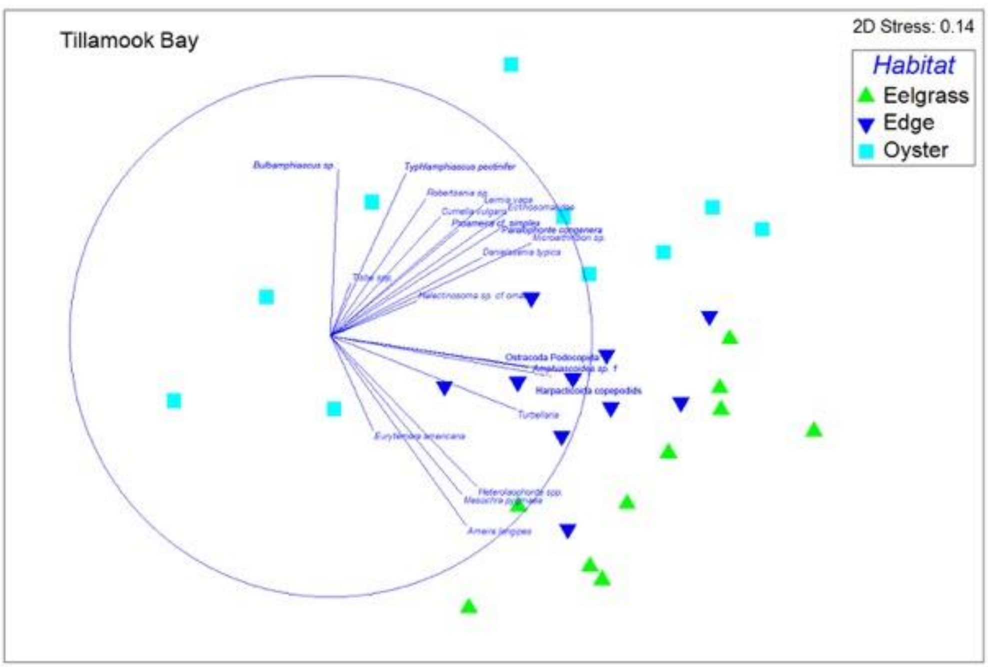


Figure 9. NMDS plots showing epibenthic assemblage structure. Symbols represent replicate samples, and vectors indicate taxa with significant gradients in ordination space based on Pearson's correlation coefficents >0.2.

As indicated earlier, part of the interest of working in Tillamook Bay is that it harbors longline aquaculture facilities. This allows us to compare our results with those obtained in other estuaries along the Pacific Northwest, providing a wider perspective and understanding of the processes regulating the interaction between eelgrass beds and aquaculture (project funded by the NOAA Saltonstall Kennedy program; reference NOAA-NMFS-FHQ-2015-2004246). In this context, it is interesting to highlight that Tillamook Bay and Willapa Bay have a higher abundance of fauna than Humboldt Bay and Samish. Furthermore, in the two former estuaries there is a pattern of decreasing abundance from eelgrass to oyster culture habitat for both total invertebrates as well as for harpacticoid copepods (Figure 10).

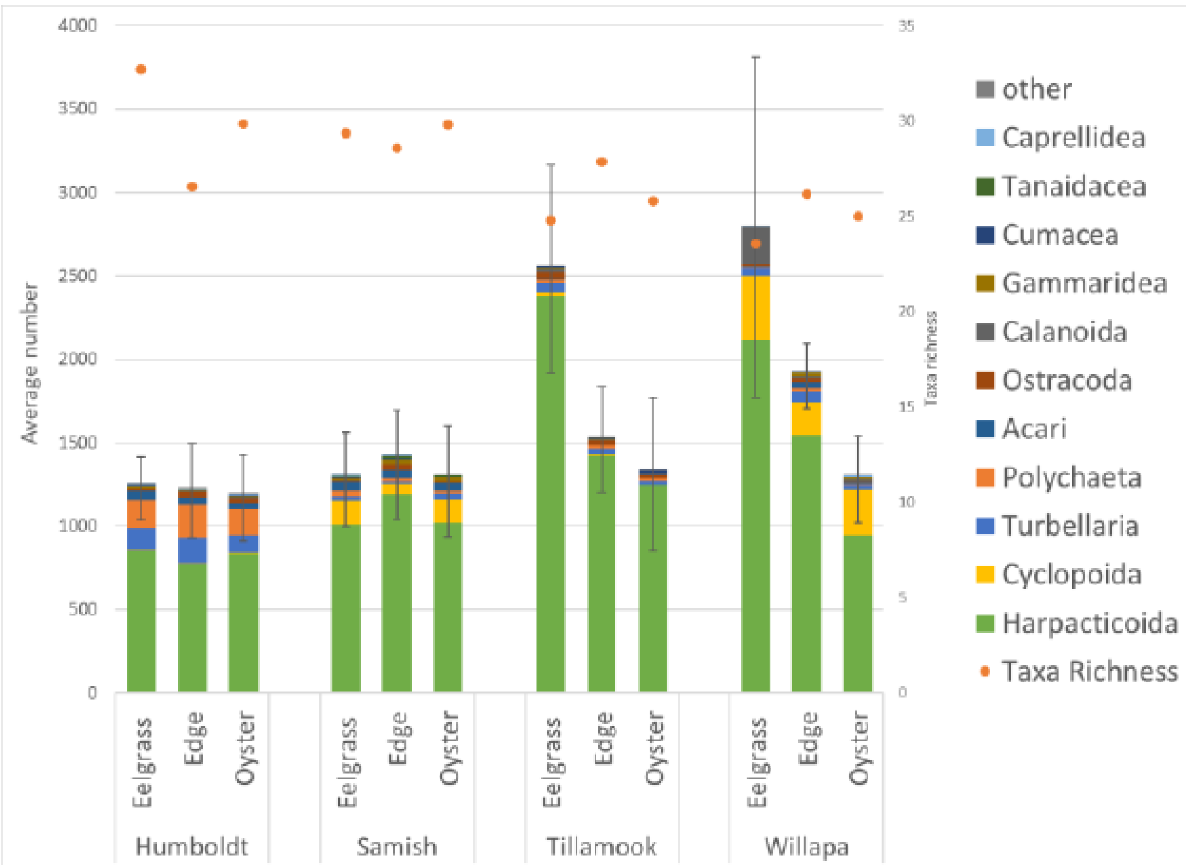


Figure 10. Abundance of major groups of epibenthic animals sampled in 2016 in Humboldt Bay (CA), Samish Bay (WA), Tillamook Bay (OR), and Willapa Bay (WA).

Minnow Traps

Large (1m x 1m x 1m) minnow traps with fyke openings on opposite sides (Figure 11) were used to assess fish and invertebrate abundance and verify species seen in underwater video (see below). In 2016, three minnow traps were deployed in each habitat at low tide (9 total) at each site and retrieved after high tide at the same time that video cameras were retrieved (approximately 4-hour fishing duration). In 2017 one of these traps was placed parallel with each major point along the transect (A-E) about 10-12 paces (approximately 5-6m) from the transect tape. These traps were un-baited. Traps were deployed at low tide and retrieved approximately one hour after the local high tide.

Figure 11. Minnow traps (approximately 1m x 1m x 1m) were used to capture fish and invertebrates in each of three habitat types. All captured individuals were identified, measured and released live in the field.

All fish and invertebrates captured were identified to species if possible, counted and released on site. Most were also measured (fish = total length or fork length, crabs = carapace width using a measuring board and calipers respectfully). Common species captured included Staghorn sculpin (*Leptocottus armatus*), shiner perch (*Cymatogaster aggregata*), juvenile English Sole (*Parophrys vetulis*), juvenile Dungeness crab (*Metacarcinus magister*), shore crabs (Hemigrapsus oregonensis), and threespine stickelback (*Gasterosteus aculeatus*). Overall, trap catches were low for most species, with highest counts recorded for shiner perch, Pacific staghorn sculpin, and shore crab. The abundance of these three species did not differ amongst habitats in 2016 (Figure 12).

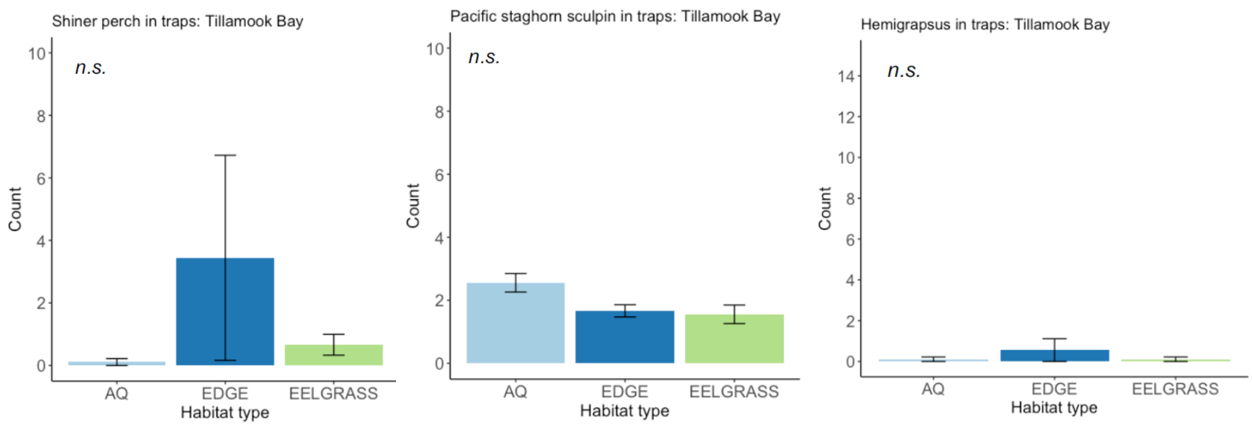


Figure 12. Mean counts (+ 1 SE) of shiner perch (*Cymatogaster aggregata*), juvenile English Sole (*Parophrys vetulis*) and shore crab (*Hemigrapsus oregonensis*), from minnow traps in Tillamook Bay in 2016. n.s. = no statistically significant differences amongst groups.

Consistent with results obtained for the 2016 sampling, total abundances and species richness of fauna found in the traps in 2017 were similar between habitats, being values of abundance less variable in aquaculture than in edge or eelgrass (Figure 13).

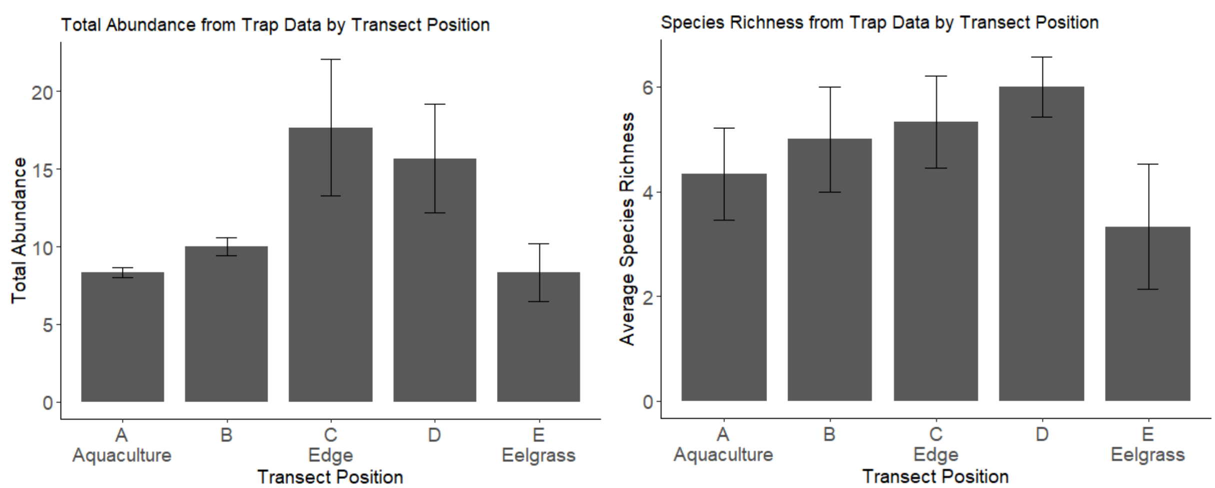


Figure 13. Mean abundance (+ 1 SE) of all organisms found in minnow traps in Tillamook Bay in 2017.

Underwater video

In 2016, video surveys were conducted using GoPro 4 ® cameras mounted to PVC pipe mounts with a top camera facing downward and a second camera on the vertical PVC arm looking outward (Figure 14). While we initially proposed using fyke nets to concentrate and observe fish with video some experimental trials conducted in Yaquina Bay suggested this would be difficult due to nets blocking field of view and camera entanglement. The additional bias due to fish attraction to the net structures and permitting issues raised by agencies, caused us to abandon this approach. Snorkelers deployed 3 camera mounts to each habitat type, 9 in total. The cameras were allowed to run for approximately 2 hours during the high tide and were retrieved via boat and gaff hook from the vessel at the end of the 2-hour deployment. In 2017, video cameras were placed but weather conditions were very bad, precluding us from obtaining any useful images due to high turbidity.

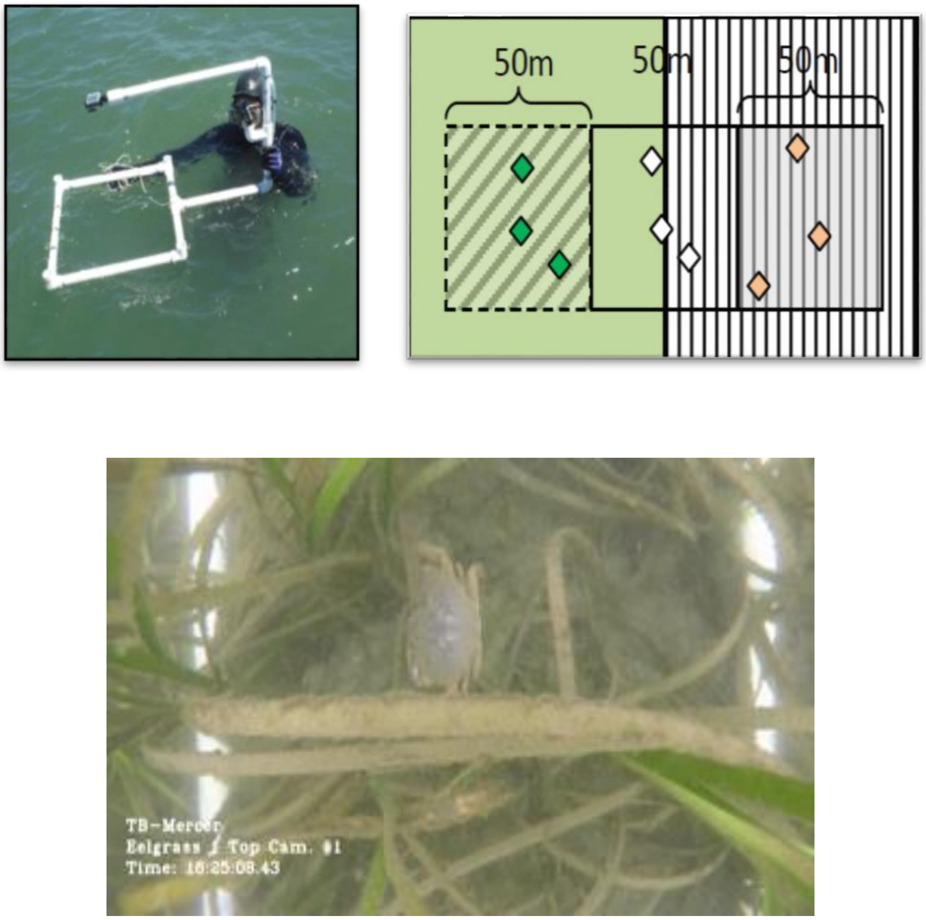


Figure 14. Video deployment on and between eelgrass and shellfish habitats and (below) screenshot from video survey of Dungeness crab utilizing eelgrass habitat

After an initial quality index review of the videos, it was decided to analyze the middle 1 hour of video for species, abundance, and several basic behavior categories. Species identification was determined using guides and were marked in the notes when the viewer was uncertain. BORIS, a free software program available online (http://www.boris.unito.it/) was used to code species and behavior categories.

The frame of reference to quantify fish and crab in the x direction is the full camera view and in the y direction is to the edge of the quadrat. This means that an individual that is outside of the quadrat on the side will still be counted, however an individual that goes behind the far arm of the quadrat will not. For each count, a key is entered into BORIS that will enter both the species and the assumed behavior. This data is then saved and exported to R for statistical analyses. Because it is challenging to know whether the same fish or crab is repeatedly visiting the site, the counts may be artificially inflated. Therefore, "sightings" has been used as the response rather than counts (which still may equal the number of counts, but referring to observations as sightings is more true to the data that has been collected).

A list of 15 species was compiled being observed in the videos: English sole, lingcod, shiner perch, threespine stickleback, Pacific herring, tubesnout, surf smelt, Chinook, Coho, starry flounder, Pacific staghorn sculpin, kelp perch, striped seaperch, red rock crab, Dungeness crab. Shiner Perch were the most sighted fish in the videos, and there were no significant differences in abundances between habitats nor between estuaries (Figure 15). On the other hand, there were differences in sightings of Pacific Staghorn Sculpin and Dungeness crabs between estuaries (much lower in Samish Bay than in Tillamook or Willapa). Furthermore, in Tillamook Bay, both Pacific Staghorn Sculpin and Dungeness crab tended to be more observed in the aquaculture habitat than in the other habitats.

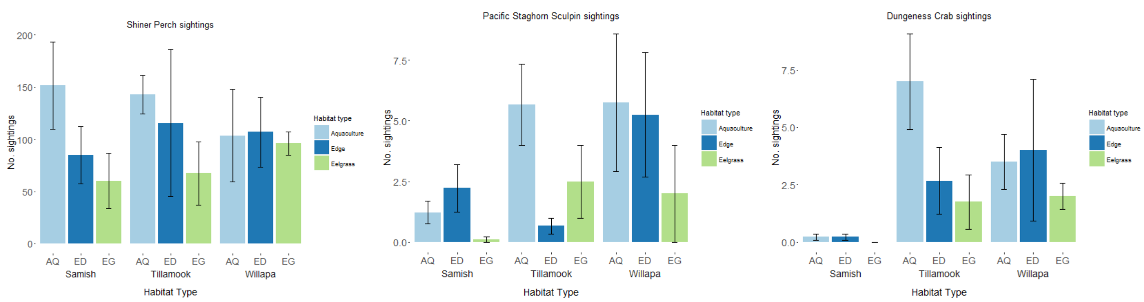


Figure 15. Mean sightings (+ 1 SE) of shiner perch (*Cymatogaster aggregata*), Staghorn sculpin (*Leptocottus armatus*), and Dungeness crab (*Metacarcinus magister*), observed in the videos recorded in summer 2016 in Tillamook Bay (OR), Samish Bay (WA) and Willapa Bay (WA).

In addition, the following behavior categories were quantified:

1. Transit: movement in and out of frame with no other apparent objectives.
2. Forage: using predatory or herbivorous tactics to ingest food
3. Fight: aggression between one or more species
4. School: “an aggregation formed when one fish reacts to one or more other fish by staying near them” (Keenleyside 1955)
5. Refuge: using structure to hide from predators or predators seeking vegetated areas where prey are present
6. Other

Regarding behavior, patters observed were mostly driven by shiner perch, as they were the most commonly observed species. As it can be seen in Figure 16, transit and schooling were the most common behaviors. No strong differences in behavior were detected between habitats, although the edge habitat and, particularly, in Tillamook Bay, is the habitat exhibiting more diversity of behaviors (Figure 16).

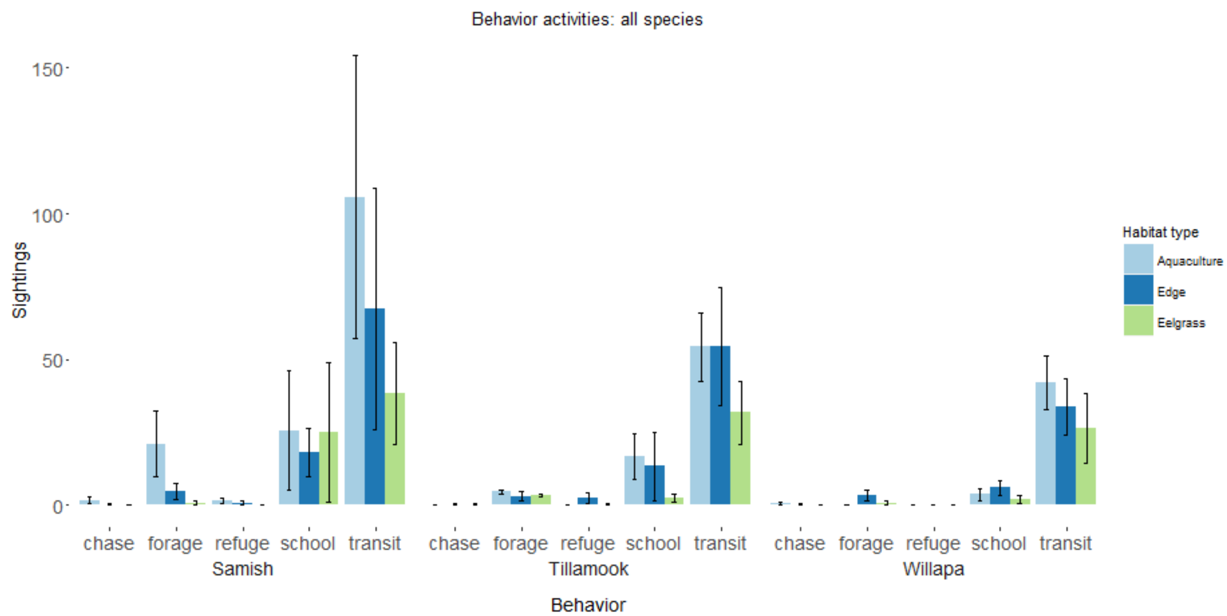


Figure 16. Mean sightings (+ 1 SE) of shiner perch (*Cymatogaster aggregata*), Staghorn sculpin (*Leptocottus armatus*), and Dungeness crab (*Metacarcinus magister*) performing different types of behaviors, observed in the videos recorded in summer 2016 in Tillamook Bay (OR), Samish Bay (WA) and Willapa Bay (WA).

Fish counts: due to poor water visibility both in 2016 and 207, direct visual surveys of fish with snorkel observations were not performed.

Tethering experiments

Predation tethering units (PTUs, Figure 17) were used to assess relative predation rate in each habitat type. In 2016, a PTU was placed at each of the 20 quadrat locations on the opposite side of the transect from the quadrat as to not disturb the eelgrass sampling. Two to three treatments were placed: a standard squid square that hung 30cm from the sediment, a standard squid square that sat on the sediment surface, and at one site, a mud or Dungeness crab (10-20 cm CL). Once all PTUs were deployed, they were checked at intervals and squid/crab presence/absence was recorded. In several instances, the PTU was checked and a sculpin or crab were observed eating the squid bait, which were recorded. Changing incoming tide rates were a challenge for determination of presence/absence checks of the PTUs and varied sometimes between habitat types depending on tidal elevation. In 2017 only squid bait was used and two different treatments of PTUs ("high" and "low") were used. The high treatment had the squid bait (diameter = ½ in, 1.27cm) superglued to a 10cm monofilament line and tied at 30cm above the substrate, while the low treatment had the bait tied at 10cm up the stake to a 10cm line so that the squid sat on the substrate. These two different treatments were meant to assess different types of predators within the system: those that were swimming and predating within the water column and those that were searching for prey along the bottom substrate. At each of the five main points along the transect, 5 PTUs of each treatment were deployed. The stakes were placed in two rows approximately 1 to 2 meters width apart, alternating high and low treatment within each row. The first set at each point was placed about 5 paces from the transect tape, so as to not influence other sampling techniques. The presence of the squid bait was checked once the water had reached a depth of about 30cm (height of the knot on the high treatment) and then a second time approximately 24 hours later.

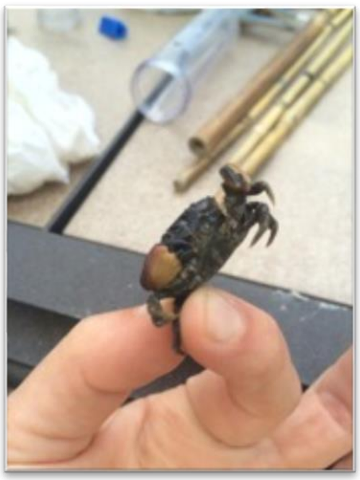
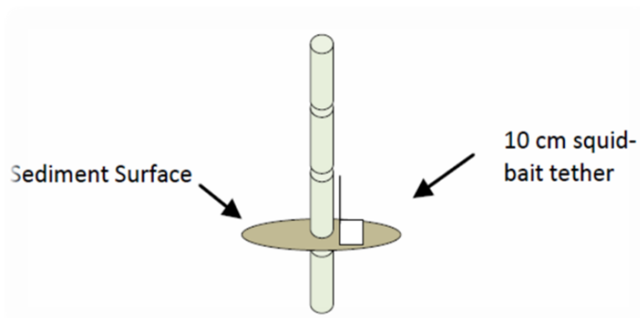


Figure 17. Predation tethering units (PTU's, right) consisted of bamboo poles with small pieces of squid bait or alternatively live tethered crab (like the shore crab depicted above) attached to monofilament line at two distances from the sediment surface.



Results of predation experiments indicate that predation does not differ amongst habitat types (Figure 18). There were strong differences in predation between times (i.e. ca. 1-2 hours vs. 24 hours after deployment) and between estuaries. Interestingly, Tillamook exhibits the highest predation rate in comparison to Humboldt and Samish. Furthermore, whereas in Samish and Humboldt there are significant differences in predation pressure between the high and the low tethers, predation is very high at both levels in Tillamook. These results suggest that Tillamook harbors an important community of both bottom as well as water column predators, whereas predation by water column predators is lower in Humboldt and Samish.

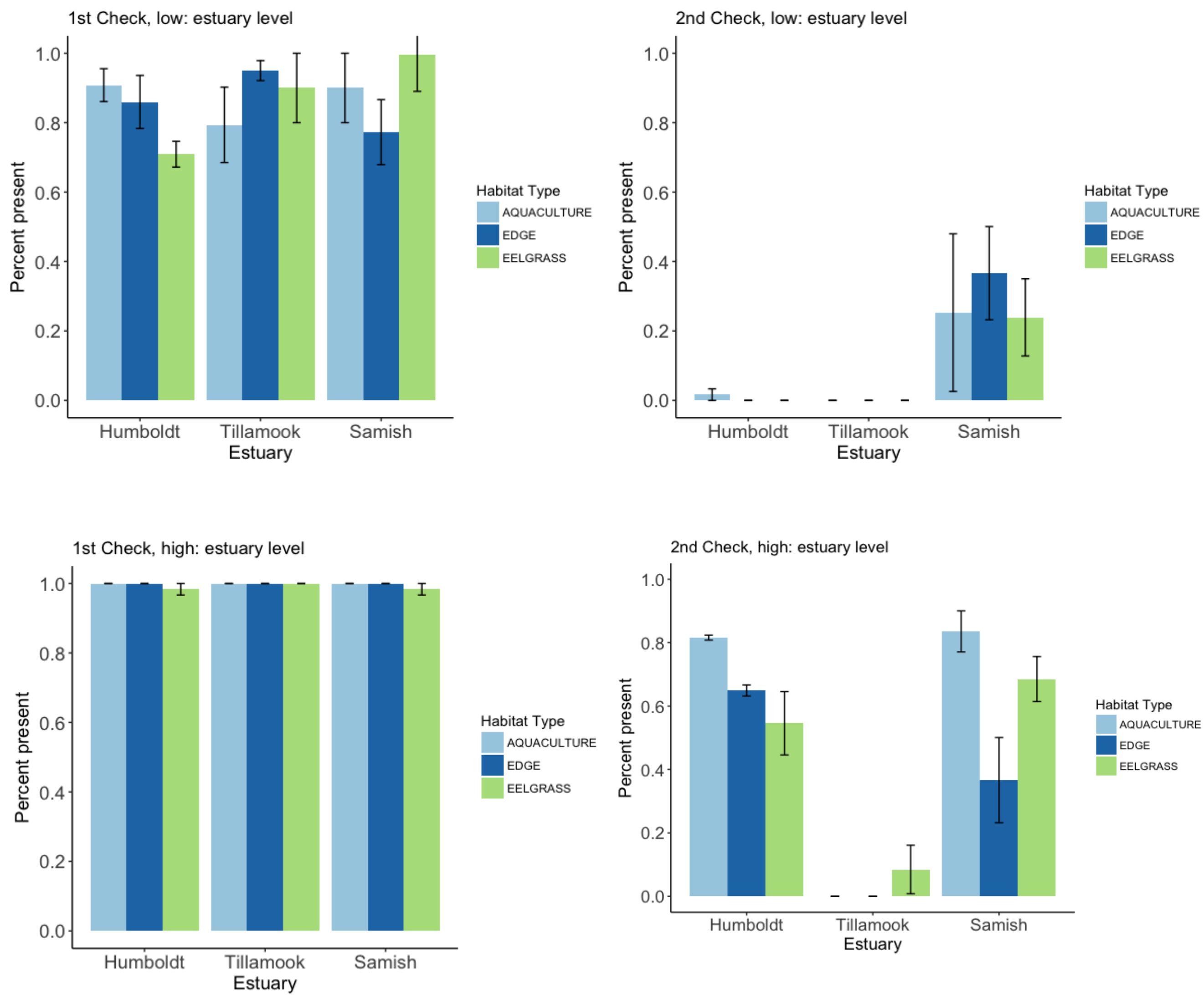


Figure 18: Mean percent (±1 SE) presence of the low (above) and high (below) squid bait present on PTUs at the first check (left) and second check 24 hours later (right) at 3 sites per estuary.

A similar pattern was observed for Tillamook with the 2017 data (no comparison with other estuaries available), with similar (and high) predation pressure across habitats (Figure 19).

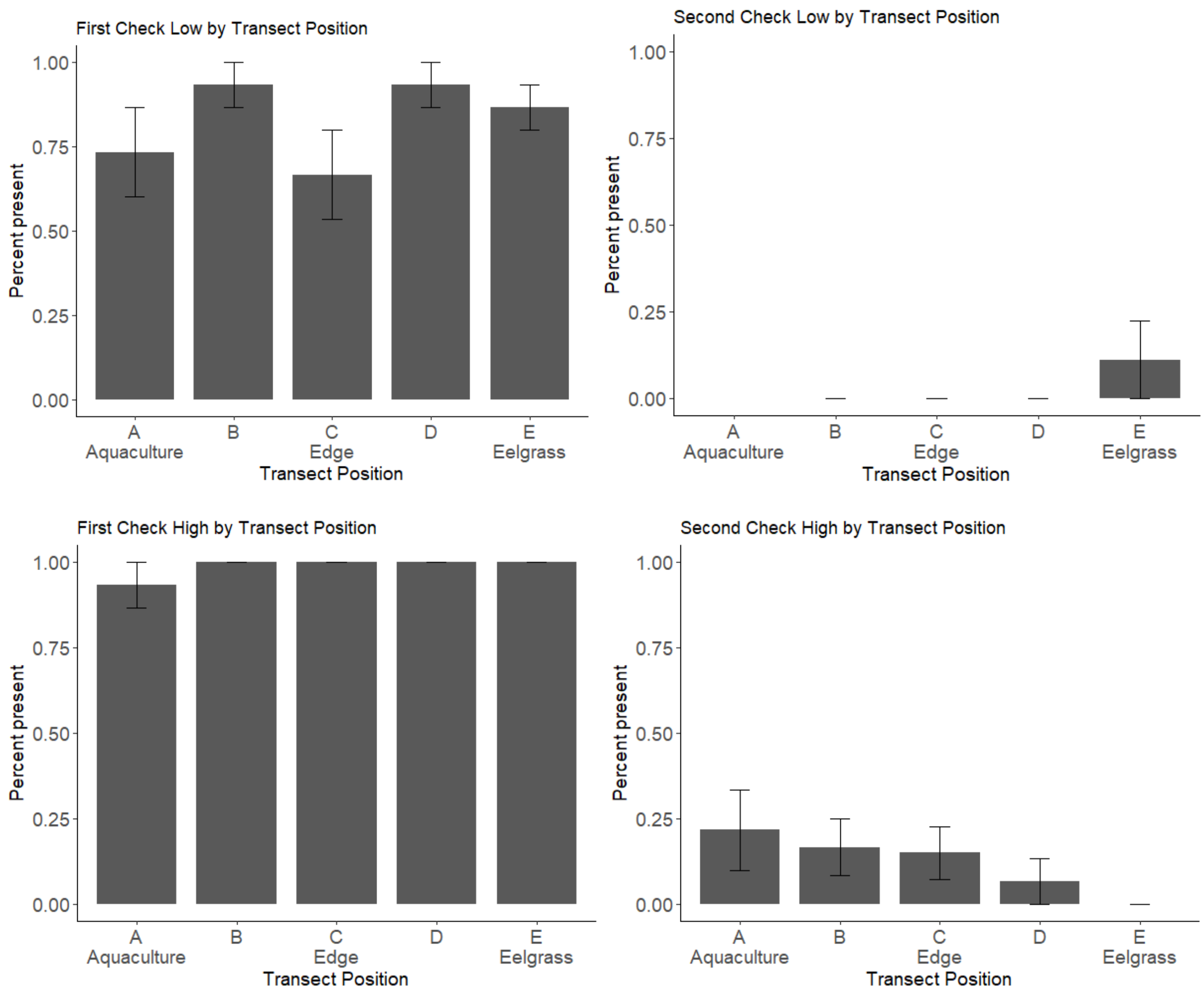


Figure 19: Mean percent (±1 SE) presence of the low (above) and high (below) squid bait present on PTUs at the first check (left) and second check 24 hours later (right) along the transects across habitats in Tillamook Bay in 2017.

Conclusion

Most of the activities related to Tasks 1 and 2 have been completed, except for processing of the seagrass samples from 2017 and the posterior data analyses. I therefore asked for a no-cost extension in order to complete these activities, which we expect to be finalized by August 31st 2018.

Data obtained thus far suggests that aquaculture can have negative impacts on abundance of seagrass, which is in accordance with previous works (e.g. Tallis et al. 2009, Wagner et al. 2012, Skinner et al. 2013). Regarding function of the different habitats, both trap and video data suggest that fish and crab community are mostly similar amongst habitats. Shiner perch have previously been shown to be more abundant in eelgrass, but was not the case for Tillamook Bay. Staghorn sculpin are common predators in estuaries, and their abundances did not differ amongst habitats. In accordance with these results, we did not find strong differences in predation pressure (measured via de tethering experiments) amongst habitats. Interestingly, however, epibenthic invertebrates were more abundant in eelgrass beds than in the other habitats.

Project Presentations, Manuscripts, etc.

Clarke, L., F. Tomas Nash, and B. Dumbauld. 2016. An Examination of the Use of Seascape Scale Habitats Including Oyster Aquaculture and *Zostera marina* by Fish and Crab in US Pacific Northwest Estuaries. PCSGA/NSA annual conference, presentation, Lake Chelan, Wa.

Clarke, L., F. Tomas Nash, and B. Dumbauld. 2016. An Examination of the Use of Seascape Scale Habitats Including Oyster Aquaculture and *Zostera marina* by Fish and Crab in US Pacific Northwest Estuaries. State of The Coast Conference, poster presentation, Lincoln City, Oregon.

Clarke, L. M. 2017. Functional comparison of longline oyster aquaculture and eelgrass (*Zostera marina L.)* habitats among Pacific Northwest estuaries, USA. MS thesis, Oregon State University 71p.

Dumbauld, B., L. Clarke, Muething, F. Tomas Nash, and B. Hudson. 2017. Do fish recognize shellfish aquaculture and eelgrass as intertidal landscape features and can we tell? PCSGA/NSA-PCS Annual Conference, , presentation, Welches, Oregon.

Dumbauld, B.R. and S. Rumrill. 2017. Oysters in Oregon. State of The Coast Conference, panel presentation, Florence, Oregon.

Hudson, B. 2017. Aquaculture & Eelgrass, Does Habitat Suitability Differ for West Coast Species of Interest? PCSGA/NSA-PCS Annual Conference, presentation, Welches, Oregon.

Muething, K., F. Tomas Nash, and B. Dumbauld. 2017. Comparing fish and crab use of the aquaculture/eelgrass (*Zostera marina*) boundary for two different methods of Pacific oyster (*Crassostrea gigas*) aquaculture. State of The Coast Conference, poster presentation, Florence, Oregon

Muething, K, and B. Dumbauld. 2018. Comparing fish and crab use of the boundary between two types of pacific oyster aquaculture and eelgrass in Willapa Bay, Washington, USA. National Shellfish Association 110th Annual Meeting, presentation, Seattle, WA, USA.

B. Dumbauld. 2018 some considerations for evaluating oyster – seagrass interactions
At broader scales in us west coast estuaries. National Shellfish Association 110th Annual Meeting, presentation, Seattle, WA, USA.

Cheney D, Hudson B, Dumbauld B, Cordell J, Tomas Nash F, Kramer. 2018. Quantifying ecosystem functions in mixed oyster culture and seagrass / macroalgal habitats. National Shellfish Association 110th Annual Meeting, presentation, Seattle, WA, USA.

BENEFITS & IMPACT:

Natural resource management has largely relied on sector-based approaches to regulate practices surrounding specific natural resources. Within estuarine systems, this means that fisheries have been managed separately from transportation and recreation and even aquaculture, among others. The regulatory conflict between shellfish aquaculture and eelgrass in different areas of the PNW is one example of how this sector-based management can become problematic. Because neither of these interests exists in isolation but are actually closely connected to the other in space, managing them separately can often make the issue more complicated. In fact, within different states there are multiple federal, state, and local agencies that have regulations around the establishment of new aquaculture near eelgrass beds. This means that groups seeking to obtain a permit for shellfish aquaculture must go through a tedious, bureaucratic process that can often be time-consuming, expensive, and confusing. Of particular interest here, these agencies also have inconsistent regulations around establishment of commercial aquaculture in or near eelgrass beds. For example, the US ACOE in consultation with the National Marine Fisheries Service, an agency under NOAA, uses a 16 horizontal foot buffer between native eelgrass beds and new aquaculture activities (US Army Corps of Engineers 2017). However, according to the Pacific Fishery Management Council, which designates “essential fish habitat” for fisheries along the West Coast, new aquaculture should not occur within 25-30ft of existing eelgrass (Pacific Fishery Management Council 2014). These examples help to illustrate the complex regulatory environment surrounding shellfish aquaculture within the PNW, especially as it relates to eelgrass. To appropriately consider the myriad connections between aquaculture and eelgrass, a new type of management style may be necessary.

Ecosystem-based management (EBM) has received increasing attention in recent years as a way to account for the variety of human pressures that coexist in natural systems. In general, EBM is a strategy which strives to preserve the health, productivity, and resilience of an ecosystem for the benefit of services important to humans (COMPASS 2005). It recognizes the interconnectedness between different natural processes as well as between humans and the environment. By conducting shellfish aquaculture and conserving eelgrass beds within estuaries, humans become a part of the coupled socio-ecological system (McLeod and Leslie 2009). This designation recognizes that humans are not just external agents, but closely connected to the functioning of natural systems (Berkes 2012). Thus, EBM would give a platform on which to consider a way for human interests like shellfish aquaculture and eelgrass preservation to coexist with natural processes. The other key component of EBM that is of importance here is a focus on the particular location under management. The root of the issue between shellfish aquaculture and eelgrass is that they often overlap in spatial extent. By focusing on a specific place rather than a sector or industry, EBM inherently considers the connections that occur because of proximity. In the case of shellfish aquaculture and eelgrass, this would allow for a more explicit consideration of the trade-offs between the two interests.

Both provide ecologically, economically, and culturally important services, but management of each individually does not give managers the ability to consider these trade-offs. An EBM approach to estuarine management would allow for a more realistic perspective to be adopted. In estuaries, shellfish aquaculture and eelgrass provide a clear example of how EBM could benefit the system as a whole, balancing the various interests within.

The work described here adds to the current understanding of the connections between shellfish aquaculture and eelgrass. Because of the potential for aquaculture practices to impact eelgrass, current sector-based management positions aquaculture in opposition to eelgrass. However, this research presents the possibility that certain types of shellfish aquaculture could provide habitat similar to that provided by eelgrass. In addition, it considers the edge effects present when shellfish aquaculture occurs directly adjacent to eelgrass. A more complete characterization of the pervasiveness of these edge effects could help to inform the buffer zones defined by the various state and federal agencies mentioned above. All of this information would be necessary and pertinent to the development of an EBM framework for estuaries within the PNW. Currently, the buffer zones show recognition of a connection between shellfish aquaculture and eelgrass but they inherently prioritize fisheries management (since it is through designation as "essential fish habitat" that eelgrass is protected) over aquaculture. Incorporating understanding of these connections into an ecosystem-based approach to management would give managers the ability to make decisions most appropriate for specific locations and explicitly consider the trade-offs between establishing aquaculture or conserving eelgrass.

Estuaries are highly complex systems and there is no correct answer for how to manage the various human activities and interests that occur within them. However, work like the research presented here could help to add to the "best available science" used by managers and policy-makers who make decisions about how best to use these areas. In addition, adoption of a management style founded in EBM would allow for a more cooperative and realistic approach to these complex and interconnected systems. Ultimately, there will be trade-offs between expanding shellfish aquaculture and protecting eelgrass beds within coastal estuaries. The complexities of the issue only necessitate further work and collaboration to ensure that the most appropriate decisions are made.

ADDITIONAL FUNDING RECEIVED DURING PROJECT TERM:
The goals of this research are directly related to those of the USDA-ARS shellfish ecology project being conducted by Dr. Dumbauld and Dr. Fiona Tomas Nash at the Hatfield Marine Science Center. As such USDA-ARS provided support for Dr. Dumbauld and technicians (Dacey Mercer and Daniel Sund) as well as students (L. Clarke, K. Muething) to work on this project, some goods and supplies including cameras and traps, and travel support including some lodging and per diem expenses and vehicles including boats to accomplish work in Tillamook Bay.
In addition, another Saltonstall Kennedy Program Project (NA16NMF4270254) was awarded to PSI and Dr. Dumbauld during2017, and work continuing to develop these questions of seagrass / aquaculture interactions is being performed at Humboldt Bay under this new grant.

FUTURE FUNDING POSSIBILITIES:
Other future funding possibilities include NOAA programs such as the Saltonstall Kennedy grant, but also their Aquaculture program via Oregon Sea Grant.

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