Washington Sea Grant Progress Report- April 2020

Project Title: Growing Sustainable Shellfish: Understanding the Ecological Role of Shellfish Aquaculture Using Emerging Technology

Project Number: R/SFA/N-6

Reporting Period: February 1, 2019 – January 31, 2020

Project Start Date: September 1, 2017; **Project End Date:** August 31, 2020

PROJECT OVERVIEW

Washington Sea Grant (WSG), The National Oceanographic and Atmospheric Administration (NOAA) and The Nature Conservancy (TNC) partnered with 6 shellfish growing companies and 1 Tribe on a collaborative research project to understand the ecological function of shellfish- growing areas relative to other habitats in Puget Sound. The aim of the project was for agencies, non-profits, and the industry to come together to begin addressing barriers to sustainable aquaculture growth due to public perception and the permitting process. Thus, the scientific study went beyond research to integrate education and communications approaches with a focus on: (1) empowering the shellfish industry to become citizen scientists and (2) communicating research results to a broad audience from managers and shellfish growers to the general public.

PROJECT PROGRESS

Objective 1: Characterize differences in nearshore fish and invertebrate communities associated with shellfish aquaculture habitat relative to natural eelgrass or mudflat habitat.

NOAA led field work to deploy underwater cameras at 5 farms of 3 shellfish companies in the summer of 2017. After the first summer of data collection, NOAA and TNC held a workshop at the Sea Grant Conference for Shellfish Growers (March 2018) where interested farms were invited to provide feedback and participate in the project. After the workshop, 4 additional shellfish companies joined the project allowing the research sites to expand for a second field season. In 2018, we deployed cameras at 10 farms, owned by 6 shellfish companies (and 1 Tribe) in the spring, summer and fall. Between 2017 and 2018, we captured over 460 hours of underwater footage. In addition to collecting underwater footage, we conducted eelgrass and macroalgae surveys and collected sediment cores at each camera site. We used BORIS software (https://boris.readthedocs.io/en/latest/) and the R programming environment using (R 3.6.1; R Core Team 2019) to analyze the video footage and resulting data. Eight NOAA Summer Interns assisted in field data collection providing career building opportunities for emerging scientists. We presented the project concept and project results at 8 local and national conferences. Results of the study have been compiled into a manuscript and submitted to the Journal of Applied Ecology. A synopsis of the results is provided below in the “Research Project Results” section of this report.

In addition to the research objectives of this project, we are working in collaboration with Microsoft AI for Good and AI for Earth to explore using the video data collected through this project to develop a machine learning model to automate fish detection. This machine learning technology is intended to be transferred from Microsoft to a NOAA platform (open access) to be used for research purposes by the end of 2020.

Objective 2: Empower the shellfish industry to become citizen scientists to improve understanding of the habitat value of shellfish aquaculture.

Shellfish growers engaged in the project in a variety of ways including: providing matching funds, supplying farm staff to support our research team, discussing farm ecology in the field, providing guidance on study locations, participating in project workshops, sharing stories about the benefits of collaborative research to other shellfish growers at conferences, and being interviewed for outreach materials.

One shellfish company, Riveras Shellfish, and the Jamestown S'Klallam Tribe provided an even higher level of participation by learning the full field research protocol, providing feedback on research methods, and deploying and retrieving cameras in the field. Both provided critical feedback to help refine the methods and work through camera issues in the field. After learning how to operate the underwater cameras, the Jamestown S'Klallam Natural Resource Department expressed interest in using the camera method for additional studies in the future.

A workshop was held at the PCSGA Conference in Blaine, WA in 2019 to explore collaborative research using emerging technology. Shellfish industry representatives, managers and scientists (60 total) were broken into small groups to discuss the challenges of participating in collaborative research, priority collaborative research topics, and other ways to use underwater cameras on shellfish farms. Top reasons participants thought engaging in collaborative research would be (or is) challenging were logistics and coordination. Priority research areas included: permitting barriers, shellfish-environment interactions, and carrying capacity/stocking density questions. Other research priorities that could be addressed using underwater cameras included understanding fish behavior on farms, monitoring birds, and sediment loading or transport. A full list of responses from the workshop were compiled and are provided as an attachment to the online report.

Objective 3: Using a team approach, bring to light the data collected by NOAA and shellfish growers to begin to address barriers to sustainable aquaculture growth around public perception and the permitting process.

Underwater footage provided a unique opportunity to share what life is like below the surface of Puget Sound with the public. Snapshots of flatfish, crabs, forage fish, sharks, and even a harbor seal were captured, allowing us to create exciting outreach materials to engage a wide audience. Notably, we worked with a filmmaker to create a 3.5 min film about collaborative research and sustainable aquaculture, highlighting each farm and tribe participating in the project. Extra footage was then used to create 2 additional short films for social media- one highlighting Washington Sea Grant and one focused on habitat and shellfish farms. We also made efforts to share about our project with a younger audience by developing an activity for the Seattle Aquarium's Discover Science Day and an elementary school lesson plan on fish identification and conducting underwater surveys. Sharing underwater footage and the collaborative nature of shellfish farmers through blogs, films, lesson plans and outreach events may help the public understand the complexities of life below shellfish farms in Puget Sound. A comprehensive list of our outreach activities aimed at addressing public perception of aquaculture are listed below in the "Outreach and Information Activities" section of this report.

The results of the study serve as a stepping-stone towards gaining a better understand of how fish and crabs interact with shellfish farms, an important factor that permitting agencies seek to understand if the shellfish industry is to expand in Puget Sound. Future work is already building off our findings of which species are present on aquaculture sites to better understand the ecological function of these habitats (i.e., why and/or how they are using these sites) e.g., Consortium Proposal, NOAA Project, Graduate student projects.

PROGRESS ON PROJECT OUTCOMES

Outcome 1: An empirically based understanding of the ecological/ habitat functions provided by shellfish aquaculture.	
Milestone	**Results**
Cameras deployed in shellfish aquaculture sites in south and north Puget Sound, and Hood Canal.	Cameras were deployed at 10 sites in Hood Canal, South Sound, and North Sound in 2017 and 2018 in collaboration with 6 shellfish companies and 1 Tribe.
Underwater video data uploaded to our server	Underwater video has been uploaded and backed up on NOAA Servers.
Video data analyzed for metrics of community composition and habitat use	460 hours of video were captured and a subset of the footage was analyzed by the research team.
Imagery used in educational and outreach materials.	Underwater video and imagery were used to create 3 films, 1 webstory (+1 in development), 3 blogs, 2 online articles, 2 K-12 activities, and at least 4 events. See "Outreach and Information Activities" section for details.
Results published in peer review journal using collaborative approaches to quantify the ecological functions of shellfish aquaculture	The study results have been compiled into a manuscript intended for the Journal of Applied Ecology. The manuscript is currently in the NOAA internal review process.
Results presented to industry and regulators at the WA Shellfish Growers Conference, 2019.	Study objectives, preliminary results, and/or final results have been shared at 8 local or national conferences, including the 2018 and 2019 WA Shellfish Growers Conference.
Outcome 2: Standardize methods to streamline video processing for this type of research	
Host webinar workshop to bring together specialists in the video analysis methods	The scientific community was engaged in discussions of video analysis methods at local and national conferences. Technology transfer occurred to NOAA's Northeast Fisheries Science Center, chapters of The Nature Conservancy, and University of Washington, School of Aquatic and Fisheries Sciences.
Develop methods for analysis of underwater video from shellfish and natural habitats.	Protocols to capture and analyze underwater video were developed in collaboration with shellfish growers. Protocols were made available to shellfish grower partners. We have also shared and discussed our methods with other researchers on both coasts. A community of 'underwater video' researchers is building.

	NOAA is working with Microsoft AI for Good & AI for Earth to research and develop automated fish detection models using video and data collected in this project.
Outcome 3: Transfer technology to shellfish growers willing to collect data to examine the use of nearshore habitats.	
Initiate pilot projects on shellfish aquaculture sites to train growers participants on methods of operation and data collection	Project methods were shared with all shellfish company and tribal partners. Staff at Riveras Shellfish and the Jamestown S'Klallam Tribe were trained to collect data.
Co- facilitate a workshop with interested growers on benefit of collaborating on this research	Two workshops were held to engage shellfish growers in collaborative research.
Present summary and lead discussions of pilot projects at Conference for Shellfish Growers in 2018/2019 and Washington Shellfish Initiative Meetings.	Project was presented at 5 industry-focused conferences.
Outcome 4: Collaborative research improves understanding of habitat value of shellfish aquaculture and begins to address key questions and information gaps about impediments in public perception and the permitting process.	
Conduct a brief literature review of the public's perception on the shellfish growing industry and the obstacles around habitat value within the permitting process.	A brief literature review was completed and is attached to the online report.
Develop a series of videos, infographics highlighting the science. Develop a communications strategy for release of products.	Films and infographics were created and showcased at conferences, events, and on social media accounts by TNC, WSG, and NOAA.
Collaborate with PSI to determine intersections within the permitting process.	Once results are published, we will meet with PSI and NOAA Fisheries Aquaculture coordinator to discuss implications of findings for permitting.

RESEARCH PROJECT RESULTS

Objectives for underwater video research

The purpose of this study was to determine how nearshore fish and crab communities respond to various forms of bivalve aquaculture. We used underwater video to characterize the fish and crab communities observed on three types of aquaculture practices: (1) cultured Manila clam, (2) on-bottom Pacific oyster (low structure), and (3) Pacific oysters in flipbags (high structure) sites, as well as near-by sediment and eelgrass references sites, at nine locations around Puget Sound, WA (Fig. 1). We tested the following hypotheses: (1) species diversity and richness are equal or higher in aquaculture sites relative to reference sites (mudflats/sediment or eelgrass) (2) fish and crab species naturally associated with low (small rock or mixed substrate habitat) or high (eelgrass) three-dimensional structure would occur equally or more frequently in low (clams with anti-predation nets and oyster on-bottom) or high (suspended flipbags) structured aquaculture sites; (3) fish and crab species associated with no structure (e.g., mudflats) would occur less frequently in aquaculture sites.

Methodology

We compared community composition, species diversity and richness, and species-specific observations between sites with aquaculture present and absent, between varying heights of structure, and across regions with varying amounts of naturally occurring eelgrass. Sites were monitored in nine locations across three sub-regions of Puget Sound, WA, USA in the summers of 2017 and 2018 (Fig.1). Underwater video was used to observe fish and crab species' affiliations with cultured Pacific oyster (*Crassostrea gigas*) and Manila clam (*Venerupis philippinarum*) aquaculture sites in comparison to uncultured reference sediment and eelgrass habitats (Fig. 1).

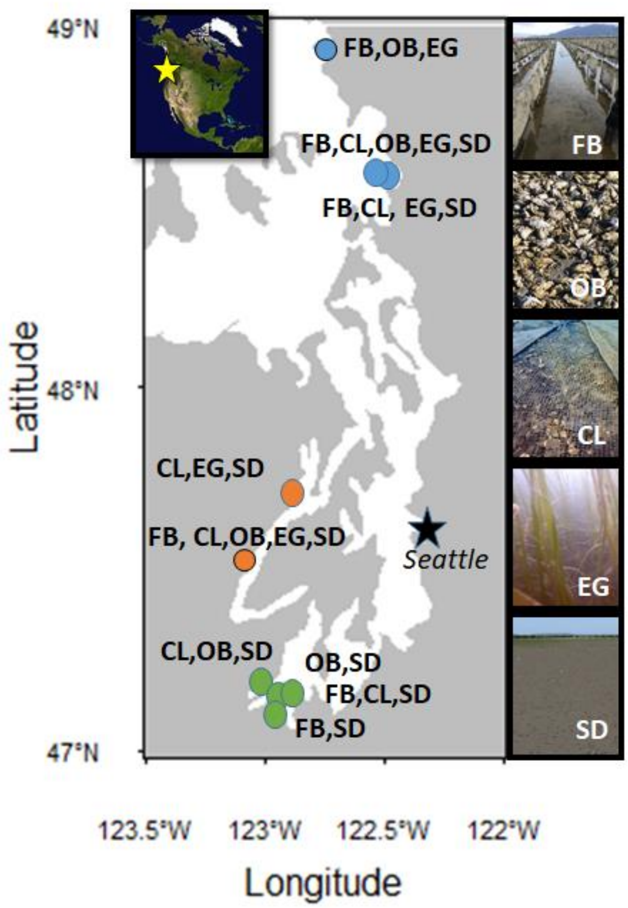

Fig. 1. A map of 9 sample sites in north (blue circles), south (green circles), and Hood Canal (orange circles), Puget Sound, WA, USA. Five habitat types were sampled approximately twice per summer in 2017 and 2018, including: Pacific oyster in flipbags (FB), Pacific oysters on-bottom (OB), Manila clams (CL), uncultured eelgrass (EG), and uncultured sediment (SD).

Rationale

Bivalve aquaculture has the potential to provide social-economic benefits to coastal communities while providing habitat function for nearshore ecosystems (Alleway *et al.* 2018; Gentry *et al.* 2019). Through the addition of structured habitat, bivalve aquaculture may provide ecological functions based on the ecological paradigm that structurally complex habitats support increased species diversity, richness, and abundance (MacArthur & MacArthur 1961). However the connection between habitat and community composition can vary by type of structure (Loke & Todd 2016), latitude (Bracewell 2018), surrounding habitat (Grabowski *et al.* 2005), scale of habitat relevant to the focal species (Loke *et al.* 2015), species group (Tews *et al.* 2004), types of complexity (Tews *et al.* 2004), and adds to the ongoing discussions of fish aggregation versus production in artificial habitat (Bohnsack 1989). Because of these uncertainties, questions remain whether this habitat complexity paradigm applies to bivalve aquaculture, and if aquaculture provides habitat functions similar to co-occurring, natural habitat structure (e.g., seagrasses) (Dumbauld *et al.* 2011).

Major findings (figures and tables)

In part, our results support the application of complex habitat theory to bivalve aquaculture, with higher or neutral abundances, and increased species diversity and richness, in some aquaculture sites, relative to mudflats and eelgrass. However, responses were generally regional- and species-specific, highlighting how a complex of local environmental and habitat conditions, aquaculture type, focal species, and vertical position in the water column, can interact to influence the response of species to bivalve aquaculture.

Overall, we found regionally-distinct associations between the fish and crab communities of Puget Sound and the habitats associated with shellfish aquaculture (Fig. 1). Of the 3038 fish and crabs observed, 98% were represented by Embiotocidae (surfperch), Cancer and smaller shore crabs, *Gasterosteus aculeatus* (three-spined stickleback), Cottidae (sculpins), and Pleuronectiformes (flatfish) (Table 1).

Table 1. Total observations of the 13 most common fish and crab species groups summed across farms, months, and years. Data were collected from June-August 2017, 2018, across three regions of Puget Sound, WA, USA.

Species/Group	Vertical Functional Group	Hood Canal	North Sound	South Sound
Surf perch (Embiotocidae)	Pelagic	244	406	1451
Unidentified crab (primarily small crabs: including shore crabs,Hemigrapsus, and juvenile Metacarcinus crabs)	Benthic	224	34	2
Crab (Metacarcinus)	Benthic	80	11	106
Three-spined stickleback (*Gasterosteus aculeatus*)	Demersal	1	181	2
Sculpin (Cottidae)	Demersal	42	58	43
Flatfish (Pleuronectiformes)	Demersal	63	19	0
Forage fish (*Clupea pallasi*, *Hypomesus pretiosus, Ammodytes hexapterus*)	Pelagic	0	4	20
Snake prickleback (*Lumpenus sagitta*)	Demersal	0	0	17
Gunnel (Pholidae)	Demersal	4	7	1
Salmonid (Salmonidae)	Pelagic	0	0	10
Bay pipefish (*Syngnathus leptorhyncus*)	Demersal	2	2	1
Greenling (Hexagrammidae)	Demersal	0	3	0

Species' affiliations with aquaculture farms varied regionally, on a scale of approximately 150km (Fig. 2a). When analyzed separately by region, the composition of fish and crab communities varied between aquaculture and reference sites in North Sound and Hood Canal (PERMANOVA, $p < 0.05$; Fig. 2b,2c), and between levels of structure (high: flipbags, low: oyster on-bottom and clam, none: sediment) in Hood Canal (PERMANOVA $p < 0.05$, Fig. 2d). In South Sound, no differences were found in community composition relative to presence of aquaculture, level of structure, or individual habitat type. Relative to mudflats and eelgrass, species diversity and richness did not change with the presence of aquaculture in

Hood Canal, increased on aquaculture sites in North Sound, and decreased on aquaculture sites in South Sound.

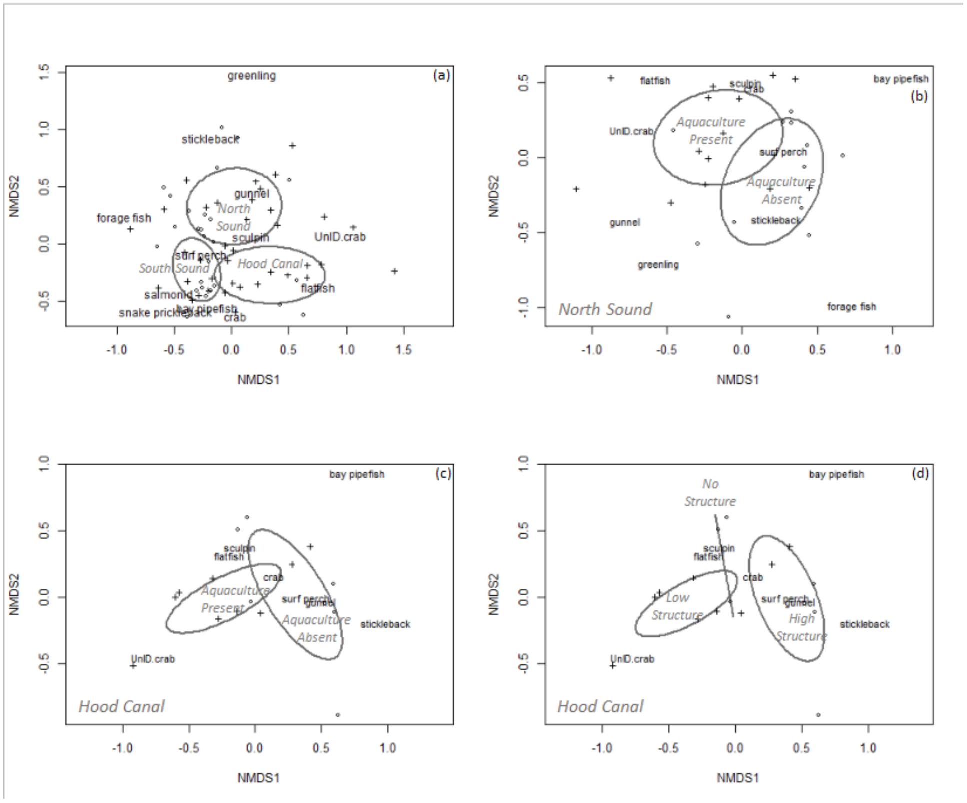

Fig.2. NMDS results showing significant variation (PERMANOVA $p < 0.1$) in community composition across three regions of Puget Sound Region (a), and related to the presence of aquaculture in North Sound (b), presence of aquaculture in Hood Canal (c), and level of structure in Hood Canal (d). Sample sites are signified by circles (non-aquaculture) and crosses (aquaculture).

Aquaculture structure height was relevant to the abundance of pelagic species, but not benthic and demersal species (Fig.3). Some presumed structure-averse species (i.e., benthic functional group and flatfish) had increased abundances in sediment (non-aquaculture/non-structured habitats) and aquaculture sites (Fig.3).

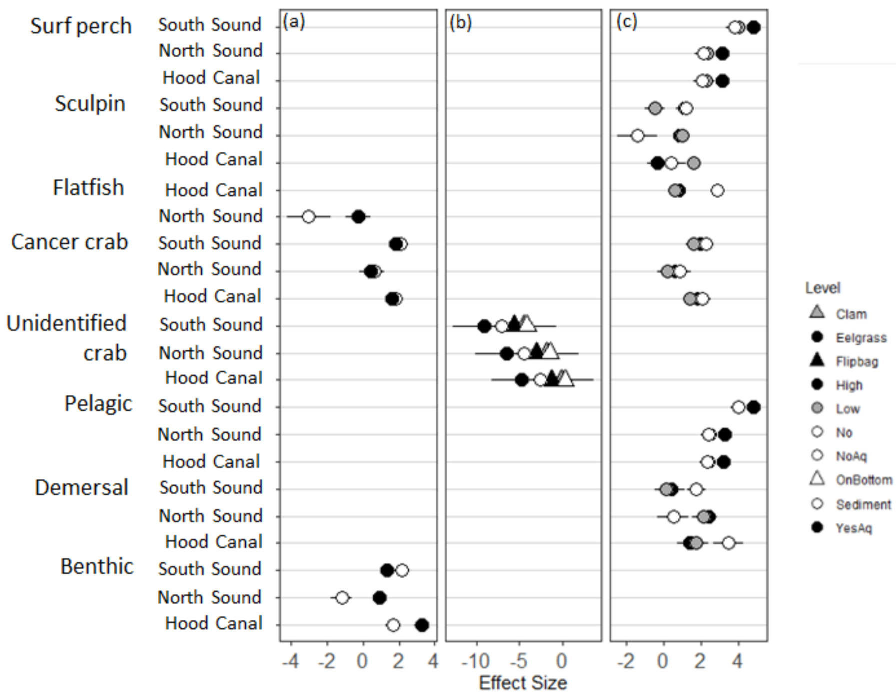

Fig. 3. Estimated effect sizes (SE) from best fit generalized mixed effect linear models that explained observed variation in abundance of surf perch, sculpin, flatfish, Cancer crab, unidentified crabs, and pelagic, demersal, and benthic functional groups. The best fit models include a fixed effect of aquaculture (a): present (black) and absent (white), habitat (b): flipbag (black triangle), clam (gray triangle), on – bottom (white triangle), eelgrass (black circle), and sediment (white circle), or structure (c): high (black), low (gray), and none (white). All models except flatfish include region (South Sound, North Sound, Hood Canal) as a fixed effect. Flatfish were analyzed separately by region (no model for South Sound).

Significance of the Results

Responses were generally regional- and species- specific, highlighting how a complex of local environmental and habitat conditions, aquaculture type, focal species, and vertical position in the water column, can interact to influence the response of species to bivalve aquaculture. Understanding the ecological mechanisms explaining these habitat relationships is the next step in predicting how an expansion of bivalve aquaculture will interact with the nearshore marine community. The habitat function of bivalve aquaculture varies by aquaculture type, focal species, and regional environmental and habitat conditions. Considering a variety of habitats, including types of aquaculture, within a region could play a role in maintaining habitat heterogeneity at the landscape level for marine organisms such as fish and crab.

OUTREACH AND INFORMATION/ TECHNOLOGY TRANSFER ACTIVITIES

Workshops/ Presentations

- Is home a place or a feeling? Fish communities in Puget Sound aquaculture habitat. WSG 25th Shellfish Growers Conference (March 2018; Alderbrook, Union, WA)
- WSG 24th Shellfish Growers Conference Workshop (March 2018; Alderbrook, Union, WA)

- How does shellfish aquaculture relate to nearshore species diversity? (Poster) Salish Sea Ecosystem Conference (April 4-6, 2018; Seattle, WA)
- Underwater Video: Pros, Cons, and Paths Forward for Collaborative Research Workshop. 72nd Annual PCSGA Conference (September 18-20, 2018; Blaine, WA)
- Pacific Shellfish Growers Association Conference. Lightening Talk: Filling knowledge gaps: partnering to see underwater and beyond. (September 18-20, 2018; Blaine, WA)
- Filling knowledge gaps: Partnering to see underwater and beyond. 72nd Annual PCSGA Conference (September 18-20, 2018; Blaine, WA)
- Collaborative Research to Understand the Ecological Role of Shellfish Aquaculture Using Underwater Video. World Aquaculture Society Meeting (March 7-11, 2019, New Orleans, LA)
- Growing Sustainable Shellfish. 26th Shellfish Growers Conference (March 2019, Alderbrook, Union, WA)
- Nearshore ecosystems: interactions of shellfish aquaculture with species and habitat. Washington Coast Shellfish Aquaculture Study Workshop (October 28, 2019, South Bend, WA)
- Adding structure to the nearshore environment: Characterizing the habitat function of bivalve aquaculture. Coastal and Estuarine Research Federation (November 3-7, 2019, Mobile, AL)

Outreach Materials

Films

- "Sustainable Shellfish Aquaculture in Washington State" (3.5 min. + 1 min. social media cut). Presented at 2 conferences and on TNC Washington's Facebook page.
- "Sustainable Shellfish Aquaculture- The Power of Partnership" (short film)
- "Sustainable Shellfish Aquaculture- Studying Underwater Habitats with Underwater Cameras" (short film)

Websites and Blogs

- Website created for TNC Shellfish Projects: http://www.washingtonnature.org/shellfish/
- Blogs: (1) Shellfish Growers Bring Pearls of Wisdom to Combating Climate Change, April 27, 2018 ,(2) Aw, Shucks: This Week, Shellfish Get Their Due, April 19, 2018, and (3) Diving for Data in Nearshore Habitats, March 9, 2018.
- Storymap: "Capturing Life on Shellfish Farms"
- Article:*"How Does Shellfish Aquaculture Interact with Puget Sound's Marine Life?" , article on Nature.org, TNC's website. Article was reposted by Sea Grant here.*
- Article: *"To Protect sensitive habitat, oyster farms turn to high-tech tools." Article on the Global Aquaculture Alliance Website. Published May 20, 2019.*

Factsheet

- A 2-page fact sheet on the project as well as an infographic describing the project.
- Conceptual figure for talks and communication developed by summer intern.

Events

- The Hama Hama Oyster Rama (2018 & 2019)- Staffed booth providing information on the project and held a "Facebook Live" event to talk about ecology on shellfish farm.
- Discover Science Weekend 2018 (Seattle Aquarium)- developed 2 outreach activities to engage children.

Science & Learning Products

- Curriculum: Teaching Unit based on nearshore fish and aquaculture (Maple Elementary School, Beacon Hill, Grade 1 class (June 2019).
- Informal literature review: “The public perceptions of shellfish aquaculture in Washington"
- Manuscript under review: “Adding structure to the nearshore environment: Characterizing the habitat function of bivalve aquaculture”

Technology Transfer

- NOAA colleagues from Northwest Fisheries Science Center in WA and the Milford Lab in New England participated in a science exchange (Sept 10-11, 2019 hosted Milford; July 1-2, 2019 visited Milford) on the use of underwater cameras on shellfish farms.
- Worked with TNC colleagues in Massachusetts to help them craft a proposal for a similar project. They are now working on a similar project with shellfish growers on the East Coast.
- Continued collaboration with Microsoft AI for Good & AI for Earth in research and development of automating fish detection in video data using video and data collected in this project. Anticipate transfer of machine learning model from Microsoft to NOAA platform (open access) by the end of 2020.

CITATIONS

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