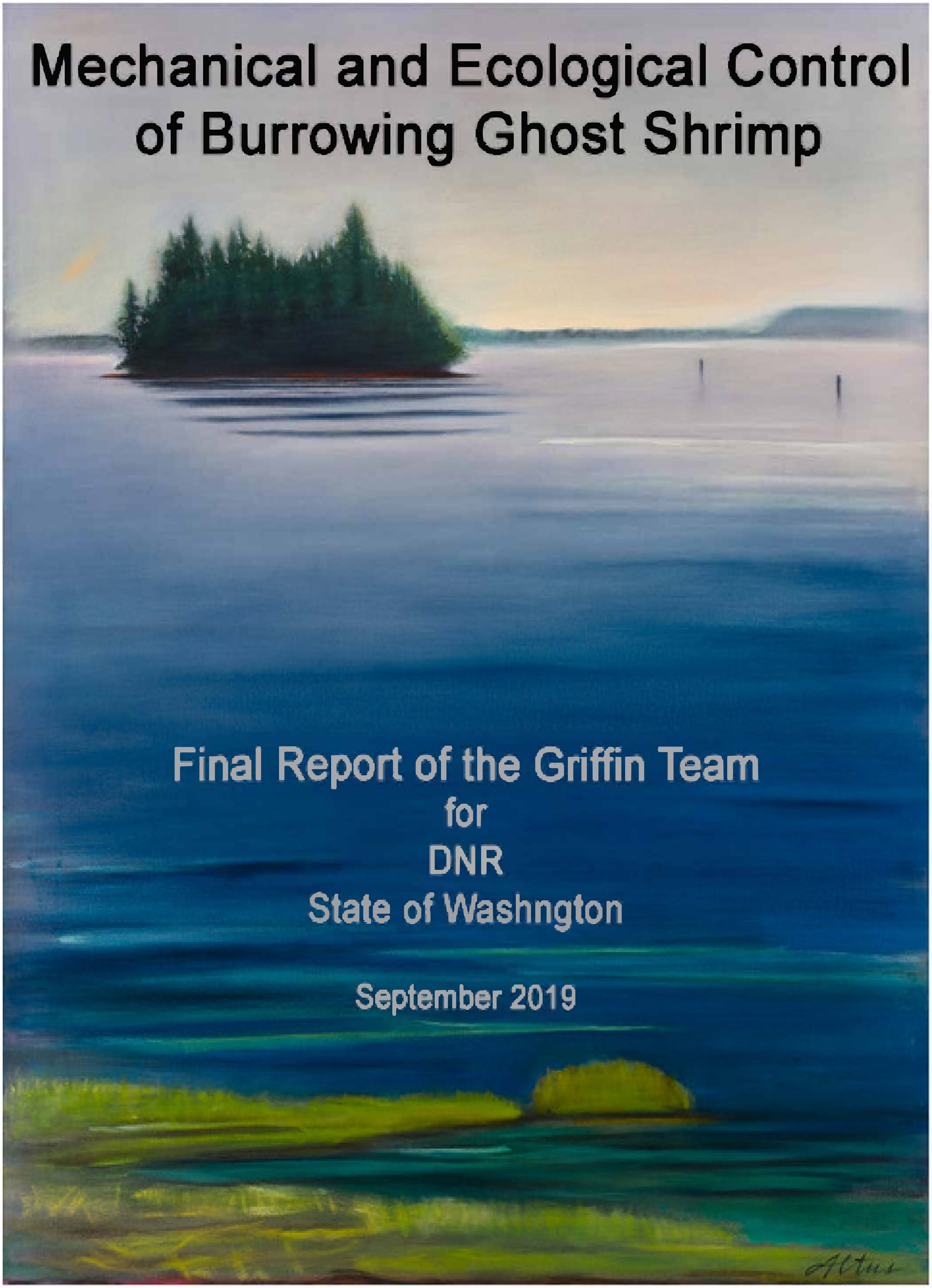
Mechanical and Ecological Control of Burrowing Ghost Shrimp



Final Report of the Griffin Team
for
DNR
State of Washngton

September 2019

Cover Painting: Willapa Bay "Baby Island"

Mechanical and Ecological Control of Burrowing Ghost Shrimp

including

Forward looking concepts for shellfish farming in Washington State

Final Report of the Griffin Team

Bainbridge Island, Washington

October 9 2019

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to

State of Washington

Department of Natural Resources (DNR)

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Contents

1. <u>Abstract</u>

A technical report providing mechanical, biological, and stakeholder policy concepts for managing the infestation of burrowing ghost shrimp (N.californiensis) in Willapa Bay and Grays Harbor, Washington State, USA.

2. Forward

The Griffin Team is pleased to propose the following mechanical and biological control concepts that will, in our professional opinion, stop the degradation of shellfish beds by the native burrowing ghost shrimp (N.californiensis). In addition, we believe these concepts will improve commercial shellfish aquaculture, create local skilled jobs, and preserve aquatic resources without the use of chemicals.

This report concludes a 5-month conceptual design engineering effort by the Griffin Team to provide buildable and testable non-chemical control concepts to the Washington State Department of Natural Resources (DNR) and the Partnership Working Group (PWG) of Willapa Bay and Grays Harbor oyster growers and stakeholders. Additional concepts address what we believe are issues important to the survival of the shellfish industry and local communities.

The recommendations are presented in three sections:

Summary of Concepts and Recommendations section is intended to inform policy makers, industry stakeholders, and the lay public with an overall view and rationale for the proposed concepts.

Technical Details of Mechanical Concepts section provides details on selected concepts with the goal of aiding professionals in further understanding, building, and implementing the proposed mechanical, operational, and technical support concepts.

Looking Forward – Climate and Ecosystem Details section presents the scientific and technical background behind promising strategies to revive natural ecosystem elements in Willapa Bay and Grays Harbor. Equally important, this section proposes research and policy actions that if adopted now, can begin to address the known and emerging effects of climate change on the coastal shellfish industry.

3. Introduction

Background

The commercial shellfish industry in Willapa Bay and Grays Harbor is based on farming two species, the Japanese oyster (*Crassostrea gigas*), first introduced in the late 1920's, and more recently, the Manila clam (*Venerupis philippinarum)*. The majority of oyster farming acreage is devoted to "on-bottom" culture of large oysters intended for local canning of oyster meat. The oysters require 3 to 4 years to reach marketable size, during which they are moved several times to take advantage of those beds most suitable for optimal growth. Transplanting and harvesting operations are done either by hand at low tide, or mechanically using a specialized vessel towing one or more dredge "baskets" along the bottom. These cultural practices and equipment are relatively unchanged since the early 1930's. (See "Oysters Have Eyes", Griffin, E., Wilberlilla, 1941).

It is estimated that 80% of the potential 10,000 acres of shellfish farming in Pacific County are used for on-bottom culture, with approximately 6,000 acres using mechanized dredging, cultivation, eelgrass control, and bed shaping.

The expansion of the Willapa Bay-Grays Harbor oyster industry following World War 2 was largely based on the increased use of oyster dredging. The disturbance of the sediment caused by anthropogenic activity may have contributed to the significant decline in eelgrass acreage seen today, as compared to the 1950's.

The loss of eelgrass, a potential natural inhibitor of the native burrowing ghost shrimp (Neotrypaea californiensis), may have contributed to the rise in shrimp populations beginning in the 1960's. In addition, the unregulated overfishing of shrimp predators, such as the green sturgeon, has removed a natural method of shrimp population control.

Insecticides (Sevin-Carbaryl) were first used to control shrimp in the 1960's and continued to be used until being banned in 2013. Several concepts and trials were conducted during the last 20 years to find mechanical or other alternatives to insecticides. Unfortunately, results from these studies were not carried further and hence no practical non-chemical control scheme, device, method, or design approaches were produced.

Purpose

The following report proposes practical tools, farming innovation, and ecosystem action that we believe will provide non-chemical solutions for the immediate and long-term management of ghost shrimp infestations. Most importantly, we believe these recommendations provide a pathway to addressing emergent climate and water quality issues.

We speculate that the extensive decay of biomass following the use of Carbaryl may in fact be "fertilizing" the sediment, and thus potentially aiding subsequent infestations. There is no direct evidence to support the speculation, but we recommend investigating the premise. We propose mechanical and biological methods that would reduce shrimp infestations and decay in three phases. Figure 1 illustrates a conceptual comparison between shrimp control by mechanical/biological methods and "extinction-biomass decay-immigration" control using chemicals or other broad band extinction concepts. Note, this figure is speculative, and is not supported by evidence.

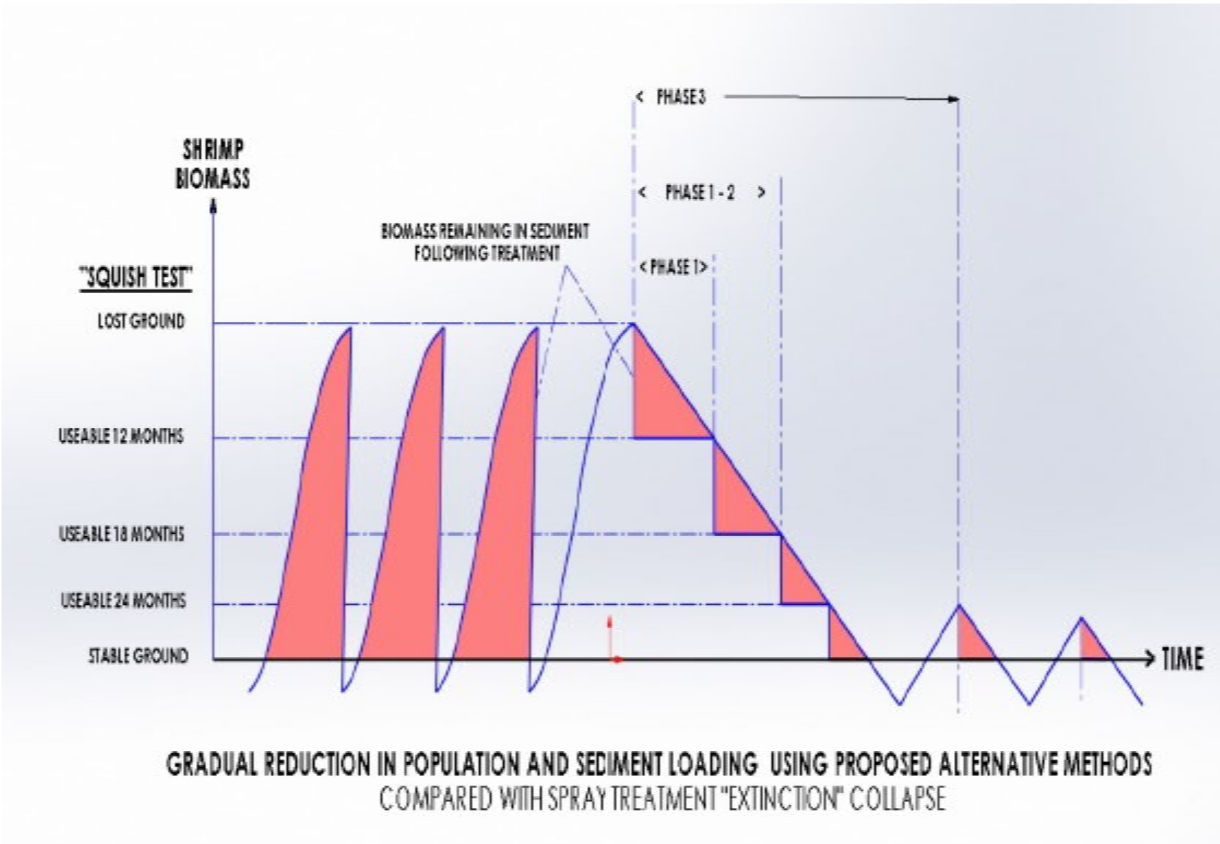


Figure 1 Recommended reduction in shrimp population compared to a pesticide extinction-biomass decay-immigration strategy

These mechanical and biological methods could, over time, reduce shrimp populations back to manageable levels using simple, practical, inexpensive equipment, techniques, and natural biological controls.

The methods we propose are promising concepts based on the best available research, experience and insights of our team, in collaboration with the knowledge and insights of a non-exhaustive list of growers who have assisted our work. These methods will require further design, testing, and investment in order to have a positive long-term effect.

Our design thinking has been guided by the need to create concepts that are as close as possible to the short-term efficacy of chemical control.

We have been guided by, and believe we have met, the majority of grower - number of growers included was non-exhaustive - and stakeholder needs, such as:

- ability to control and recover lost ground;
- ability to work over planted beds;
- lightest "touch" to the environment;
- least need for special operations;
- reduction in labor and operating costs;
- wide operating window;
- night and day operation;
- tide and season independent;
- useable and scalable to the local workboat fleet;
- simple repairable design, and buildable locally to the greatest extent possible;
- and finally, with least need for special permits and regulation.

Ghost shrimp vulnerability to mechanical control

In order to design the most efficient means to mechanically control ghost shrimp it is necessary to find the behavior which makes them most vulnerable to that control. The weakness in the shrimp population is inherent in several studies, stakeholder experience and indicated by anecdotal information.

Summary of ghost shrimp population density distribution in the sediment.

The depth that ghost shrimp reside in the sediment is perhaps the most important item of investigation that will lead to a successful mechanical design that can control the infestation particularly for the goal of stopping the loss of working oyster beds. In this regard we have identified two important items that can be used for this goal.

1. During their life cycle stages, and even during normal life activities, ghost shrimp sometimes reside near the surface of the sediment where they may be targeted by various machines that capture, maim or kill them.
2. Eel grass prairies or patches tend to be relatively free of ghost shrimp indicating an inverse relationship between eel grass density and ghost shrimp population (Castorani et al. 2014).

The near sediment surface behavior of ghost shrimp and eel grass complications

Scientific studies have pointed out that ghost shrimp juveniles and recruits reside within 2 to 4 inches of sediment surface. The same paper has stated that adult shrimp spend about 25% of their life near or on the surface.

Oysters, Crabs, and Burrowing Shrimp: Review of an Environmental Conflict Over Aquatic Resources and Pesticide Use in Washington State's (USA) Coastal Estuaries
Kristine l. Feldman
David A. Armstrong

Although shrimp inhabit burrows that extend up to 90 cm into the sediment, they are vulnerable to predators because shrimp often are situated near the sediment-water interface. Posey (1985) observed that ghost shrimp spent over 25% of the time within 2 cm of the entrance to their burrows, often with part of the chela lying exposed on the sediment surface. Occasionally, shrimp also have been observed crawling on the surface at low tide as well as at high tide (Posey 1985), exposing them to predation by epibenthic feeders.

Further on the same paper comments on common predators of ghost shrimp.

One of the most common predators of burrowing shrimp in the Pacific Northwest is the staghorn sculpin, Leptocottus armatus.

Other predators of burrowing shrimp identified by Posey (1985, 1986b) include cutthroat trout, Salmoclarkii, Dungeness crabs, Cancer magister, and Western gulls, Larus occidentalis.

Ample scientific and anecdotal evidence confirms that juvenile and adult burrowing shrimp are a food source for several predators, as detailed in **Appendix B – Natural predators of burrowing shrimp.** Natural predation confirms that ghost shrimp must spend part of their life cycle near the sediment/water interface where they are vulnerable to predators that cannot dig into the soil more than a couple inches. Shrimp must therefore be near or on the sediment/water interface as part of their normal lifecycle. Their presence near the surface is therefore the foundation for shrimp control by mechanical "predation".

However, other studies and experience show that frequent dredging to move or harvest oysters disrupts or destroys eel grass prairies. This is documented in the paper:

Influence of Intertidal Aquaculture on Benthic Communities in the Pacific Northwest Estuaries: Scale of Disturbance, Charles A Simenstad, et al.

However, persistent disturbance of eelgrass habitat by dredging, harrowing, and leveling for oyster culture may have more recently promoted expansion of burrowing shrimp by allowing these disturbance-oriented species to colonize stressed eelgrass habitats.

The first priority should be to reduce the ghost shrimp population on oyster and clam beds that are presently free from eelgrass and later improve the mechanical equipment and farming operations to encourage more eelgrass.

(end of Introduction)

4. Summary of concepts and recommendations

4.1. Summary of objectives

This report recommends concepts and designs that will reduce burrowing shrimp populations in phases, as opposed to the pesticide based "extinction-biomass decay-immigration" strategy shown in Figure 1.

The objectives shown below were developed along with the PWG shellfish growers, PWG industry stakeholders, and DNR scientists and administrators. Meetings were held in Olympia, Raymond, Willapa Bay, and on-line.

Objectives 1 and 2 focus on the immediate need to preserve productive oyster and clam grounds, including the task of stabilizing and recovering ground lost to shrimp infestation.

Objectives 3 through 5 focus on those concepts and actions that will, if begun now, prepare the industry and community for the future.

The recommendation we offer are based on the following objectives:

1. **Removing juvenile and adult shrimp** using mechanical devices and biological strategies, including:
   a) a Multi-tasking Oyster Harvester;
   b) a Multi-tasking Clam Harvester;
   c) Bed Conditioning Tools and methods for use singly or in combination; and
   d) Enhancement of natural predation of shrimp by finfish and other species

2. **Controlling and limiting shrimp habitat** using biological methods and mechanical approaches, including:
   a) Restoration and expansion of eelgrass meadows (Zostera marina); and
   b) Installation of shrimp blocking biodegradable bed mats seeded with eelgrass.

3. **Improving shellfish farming operations** using mechanical devices and operational methods that improve productivity and control shrimp,including:
   a) Multi-tasking Shellfish Harvester for operation over eelgrass;
   b) Multi-tasking Mobile Shellfish Harvester and New Bateaux for expanding operational area, pre-processing shellfish, and reducing harvesting time; and
   c) High-tension and Rolling long-lines and flip-bags for Off-Bottom methods

4. **Creating jobs** using public and private investment in current and future shellfish industry needs, including;
   a) Investment in local design, fabrication, and testing of the report recommendations;

b) Investment in local innovation, science, engineering, and fabrication start-ups;
c) Vocational training in new technology;
d) Investment in early technical education and problem solving.

5. **<u>Preparing for the future,</u>** using comprehensive stakeholder participation, including:
    a) Wide area and fine granulation monitoring of shellfish ecosystems;
    b) Technical and policy collaboration on current and emerging effect of climate change on shellfish ecosystems;
    c) Training and education specific to fisheries and aquaculture at all levels; and
    d) Development of a Coastal Shellfish Incubator for commercial proof-of-concept exploration of alternative culture methods.

4.2 Summary of concepts

The following is a brief summary of promising concepts and ideas that address each objective, with more complete technical details located in the **Technical Details of Mechanical Concepts** section.

Objective 1:

Removing juvenile and adult shrimp using mechanical devices and biological methods.

Figure 2 Willapa Bay - Burrowing ghost shrimp - juvenile and adult female with eggs

Goals :

- practical mechanical methods to quickly "stop the bleeding" and reverse additional loss of oyster and clam acreage on both working beds and "lost ground";
- tools that can be used in virtually all conditions in which shellfish farming currently operates;
- night, day, tide and season independent operation;
- minimal or no permitting required;
- direct control of the use of the tools by the grower or agency;
- tools specifically designed to control shrimp by modifying existing oyster farming tools, and thereby creating the least change to normal operations;
- specialized tools intended for use on marginal and "lost" beds that require focused remediation, which could also include abandoned shellfish beds, State lands, and other property; and
- concepts that provide a suite of mechanical tools and techniques that can be modified, mixed, and matched to suit specific and seasonal needs, as in land agriculture.

a) **Multi-tasking shellfish harvesters**

We believe the most promising practical mechanical concepts for controlling shrimp in Willapa Bay and Grays Harbor are a Multi-tasking Oyster Harvester and a Multi-tasking Clam Harvester. We envision new harvesters that can perform a variety of functions, including the traditional harvesting of oysters or clams, while at the same time, killing or maiming adult and juvenile shrimp using a suite of accessory tools and attachments. Most importantly the Multi-tasking Oyster Harvester could replace the current mechanical dredge (Fig 3), and thus allow the farmer to control shrimp as needed during normal harvester operations with little or no additional time on the grounds. This concept also promises to provide the backbone and basis for harvesting equipment that is more compatible with eelgrass and increases farming productivity.

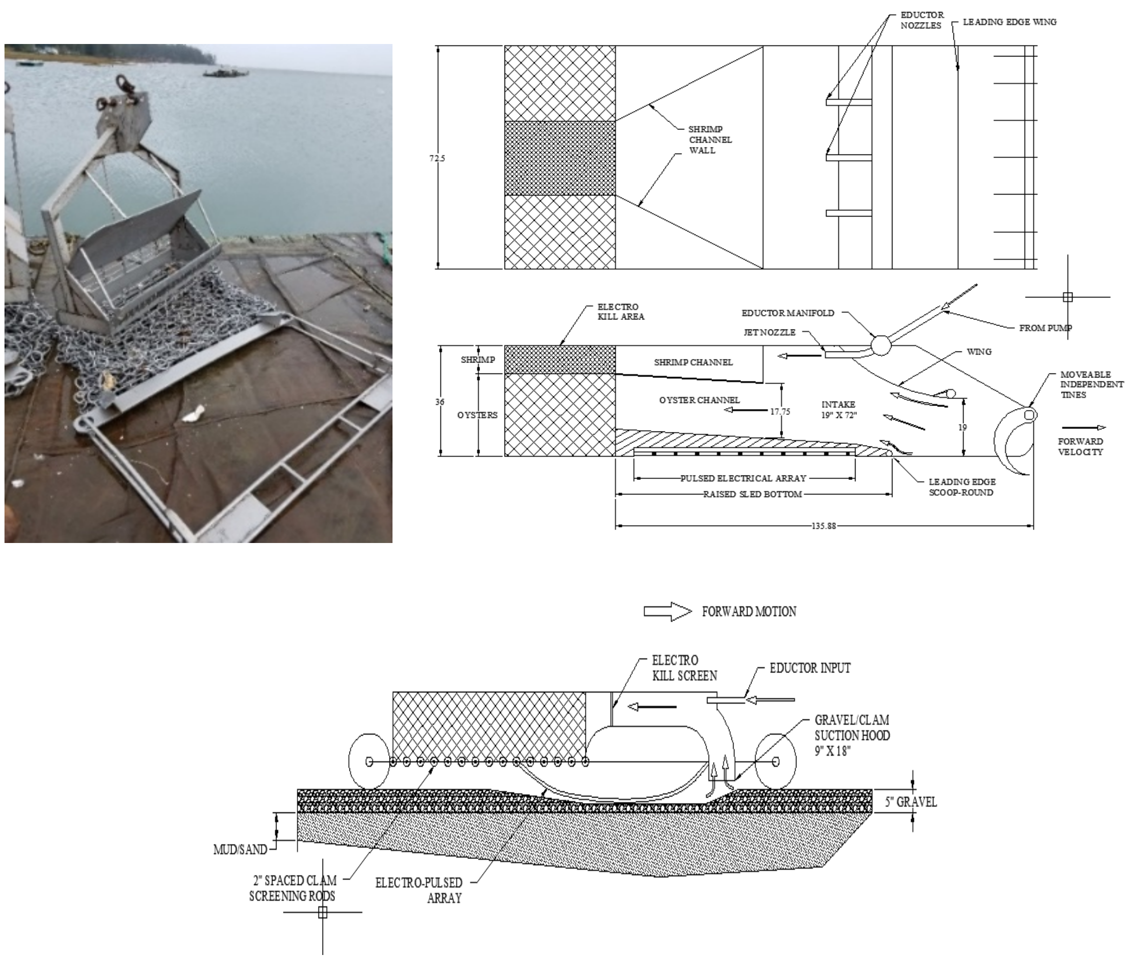


Figure 3 Traditional Willapa Bay oyster dredge and Griffin Team conceptual multi-tasking oyster harvester and clam harvester, incorporating "eductor" pump and electro-pulse technology

b) Bed Conditioning Tools

Bed conditioning tools are intended to remove, debilitate, or kill juvenile and/or adult shrimp, with minimal sediment or bio-film disruption. The choice of tool depends on whether oysters or clams are present on the ground being treated, and the extent of shrimp infestation. Most importantly, these tools can be used singly, or grouped together as part of the Multi-tasking Shellfish Harvesters mentioned previously and deployed as needed from local skiffs and workboats.

Promising tools include:

i) Rollers or heavy plates based on improvements to current DNR Proof-of-Concept device trials.

Some past tests have used rollers to compress the tidelands in Willapa Bay with the hope of reducing ghost shrimp infestation and for reclaiming ground that has been rendered too soft by the shrimp to grow oysters. These attempts are documented in photos from the 1960’s and described by participants. It was noted that behind the rollers the ground was pink with shrimp that has been pressed out of their burrows and the sea birds vigorously fed on them. More recently the proof of concept (POC) tests carried out by the state DNR essentially came up with the same results, but with detailed measurements and discussion included. The POC documented significant reduction in shrimp on the tide lands that were compressed by the roller. Both of these tests were conducted on tidelands when the tide was out and therefore will be termed dry rolling. Since both of these tests showed some good possibility of ejecting shrimp from their deep burrows, we propose to extend the technique further.

The dry rolling attempts on exposed tidelands by growers in the 1960’s and more recently by DNR proved that heavy equipment run over the tidelands did eject large adult shrimp from their burrows. Later measurements proved that dry rolling experiments showed a significant reduction in the number of live shrimp on tidelands as compared to the control plots. Though dry rolling was effective under certain circumstances, the results were limited by the following items.

1. Dry rolling was only on tidelands that were not used for growing oysters.
2. Dry rolling most probably would cause damage to clams or oysters present on the beds
3. Dry rolling experiments did not attempt to capture shrimp that were ejected and the ground pressure or roller contact in some cases did not kill the shrimp.

4. Dry rolling could cause channeling in the beds as runoff accumulated in the lower areas of the bed.
    a. Willapa Bay does have natural channels that may change with seasons or over longer time periods.
5. Favorable low tides for dry rolling mostly occur during summer days when the weather is better, whereas low tides in the winter might be accompanied by dark, wind and rainy weather.

We believe that using rollers on inter-tidal sediment that is submerged (wet rolling) may have additional advantages compared to dry rolling, as long as oysters are not present on the bed and/or when used on growing ground already completely lost to shrimp infestation. We postulate that wet rolling could be even more effective than dry rolling because shrimp ejected from the sediment will likely be floating in the water and available for capture or killing by nets, grates, or suction devices. Most importantly, dry rolling requires a specialized tractor machine, like the MarshMaster, which is limited to operating only when the tide is out. On the other hand, wet rolling can be done from existing local workboats, with wide operating areas, and with no need for specialized transportation and beach access. The best roller weight and speed across submerged sediment needs to be determined.

Figure 4 Photo of DNR POC roller and Griffin Team proposed new concepts

Wet rolling for lost ground recovery

Wet rolling, as a separate independent activity, may not have utility in everyday operations of farming productive or marginal beds. However, it has some real possibilities for strategies to recover ground lost to ghost shrimp. If wet rolling turns out to be effective, its periodic or even annual use over the same lost grounds may give eel grass prairies a chance to reform, thus improving the ecological recovery of the bay.

In the event growers choose not to replant or reclaim lost ground, an inter-agency and comprehensive stakeholder recovery strategy such as that used to control spartina grass could be employed to control shrimp infestations and restore eelgrass for the benefit of all.

ii) Chain Trawls; consisting of single or multiple lengths of specialized chain dragged along the bottom to disturb and/or redistribute the top few inches of sediment. Chain trawls could be used to turn up young ghost shrimp, so settlement is disrupted and perhaps over the long run achieving a reasonable balance of oysters and ghost shrimp.

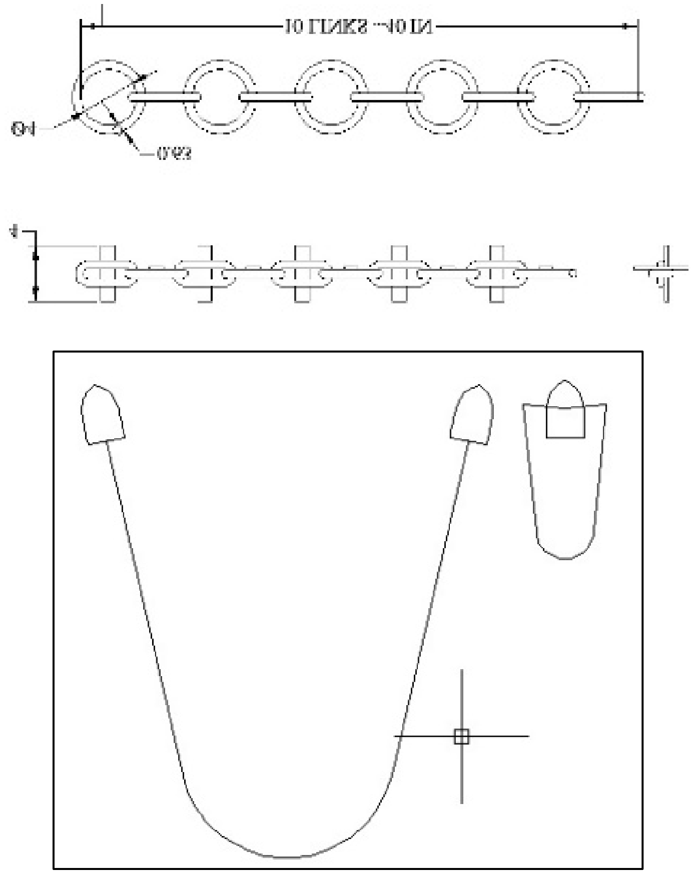


Figure 5 Chain examples and Griffin Team sketch of workboats towing long chain(s)

iii) “Eductor” pump systems; based on simple and proven sediment, debris lifting and suction systems currently in widespread use in marine applications. Eductors have potential to perform a variety of shrimp suction, bed conditioning, gravel cleaning, and harvesting functions.

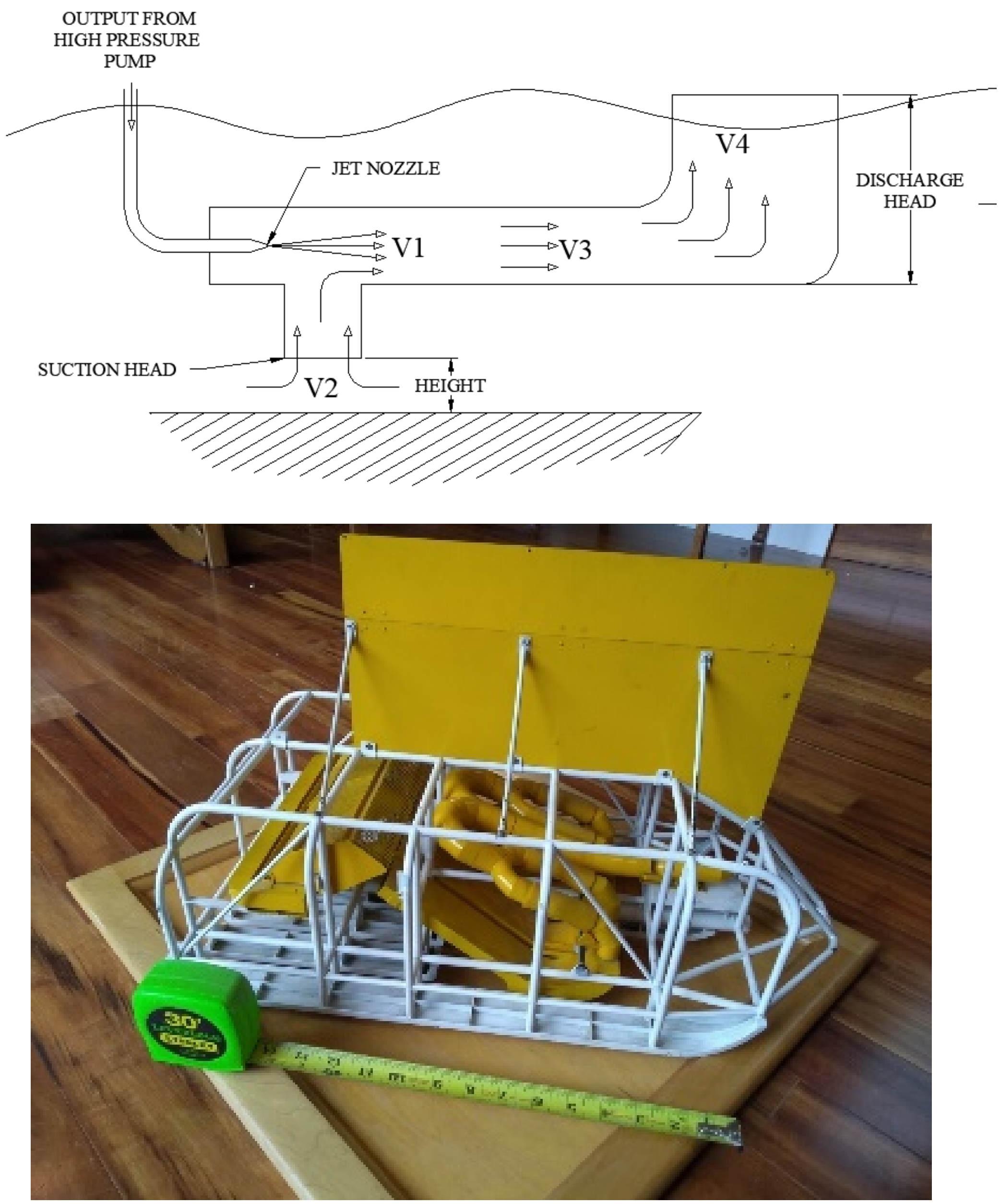


Figure 6 Physics of Eductors and model of multi-tasking Eductor sled

iv) Electro-Pulse trawling; based on Dutch electro-fishing technology.

Numerous attempts have been made to develop electrical means to catch fish or shrimp. The most successful use has been by the Dutch beam trawl fleet. The technique of electro-pulse trawling has been so successful that its use was quickly adapted by the fishing fleet and a few years afterward was banned in the European Union because of the yet unknown damage it might have on benthic creatures including shrimp. However, for our objective of finding mechanical solutions to the ghost shrimp infestation damage to the population is exactly our goal. If electrical means cannot eliminate adult ghost shrimp it is possible to limit future population growth by killing or maiming small and extra small shrimp that have been shown to live closer to the sediment surface than most adult shrimp. Some adult shrimp are sometimes near the surface where electricity may be able to kill them or adversely affect their reproductive cycle. Since electro-pulse equipment is available from EU suppliers it is worthwhile suggesting that this technique be adapted to our mechanical solutions.

Lost ground recovery

For the same reasons that wet rolling has limited utility as an independent separate tool for routine oyster operations, electro-pulse trawling may have some real possibilities for other stakeholder strategies to recover ground lost to ghost shrimp. If electro-pulse trawling turns out to be effective, its periodic or even annual use over the same lost grounds would prevent new shrimp colonization and thus when combined with natural or intentional replanting of eelgrass, help the ecological recovery of the bay. When recovery of lost ground is a goal, an inter-agency and comprehensive stake holder strategy such as was/is used to control spartina grass could be employed.

Some recent studies of electricity and its effects on benthic creatures have concentrated on the electrical effects to adult shrimp but with none yet concentrating on the effects on the earlier life stages. However, both studies cited below suggest that electro-pulse equipment might kill or maim the shrimp in their earlier life cycles. Because the electo-pulse lines are all parallel to the tow direction and relatively small and light, this technology promises to be the lightest touch of any mechanical means in terms of its disruption to eel grass.

Explanation of the pulse trawl technique is given in the following link and references 1 & 2 discuss electrical effects on marine species. Several more can be found online.

https://www.youtube.com/watch?v=cR6lmuD7X34

References

1) Determining the safety range of electrical pulses for two benthic invertebrates brown shrimp (Crangon crangon L.) and ragworm (Alitta virens S), Maarten Soetaert, et.al.
2) The Potential Use of Electricity to Control Burrowing Shrimp in Oyster Aquaculture Beds. B. Dumbauld and L. Harlan

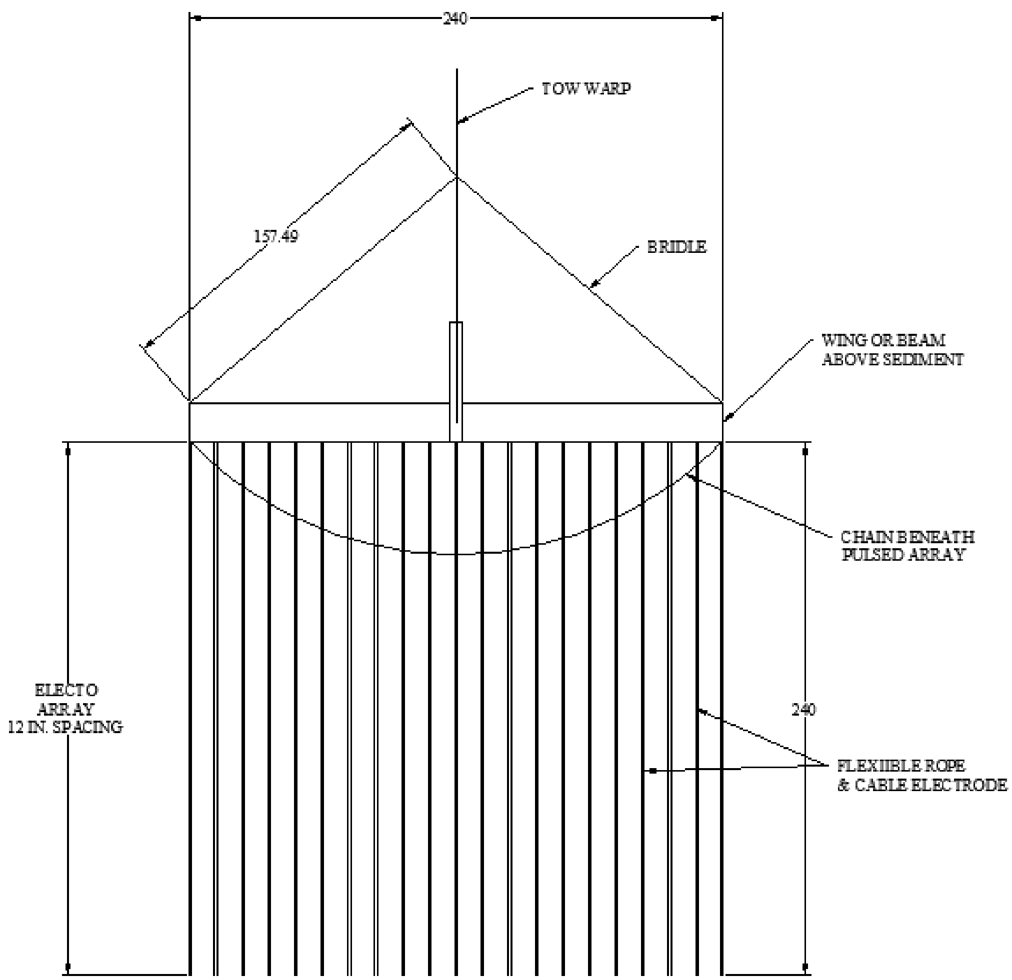


Figure 7 Dutch Pulsewing trawl and Griffin Team 20ft wide Willapa Bay Electro-Pulse concept

c) Enhancement of natural predation

Burrowing ghost shrimp have several known fish, crab, and bird predators. However, declines in finfish predator population over the past 50 years have most likely contributed to increases in shrimp populations. Restoration and enhancement of finfish predators such as the Green Sturgeon, Pacific Staghorn Sculpin, and various salmonids could reduce shrimp populations in heavily infested areas.

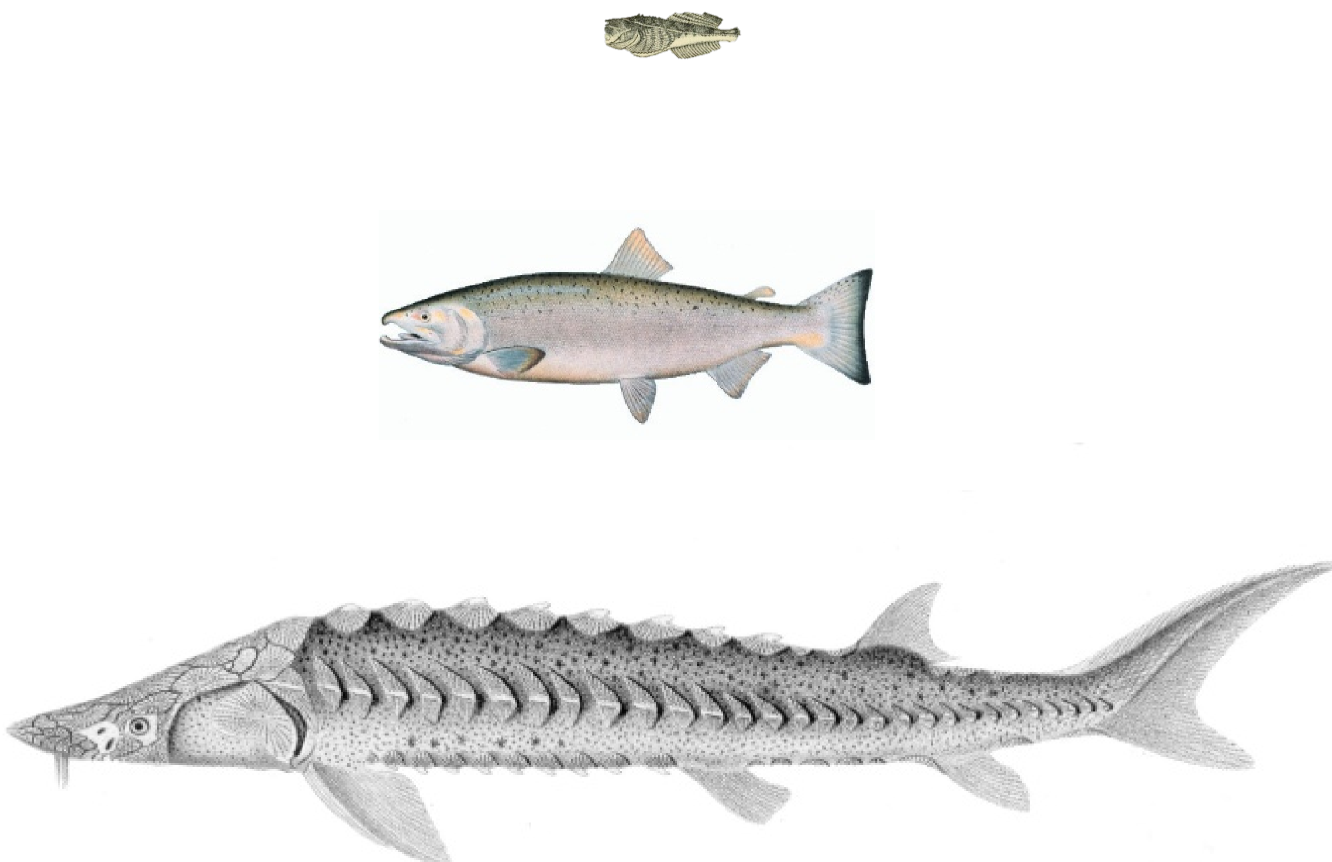


Figure 8 Burrowing ghost shrimp predators include Pacific staghorn sculpin, Pacific Coho Salmon, and Green Sturgeon

Objective 2:

Controlling and limiting shrimp habitat using biological and mechanical methods.

Goals:

- Low-cost long-term shrimp control
- Ability to treat bare and infested “patches” in existing productive beds
- Ability to use in combination with off-bottom methods
- Development of Multi-tasking shellfish harvesters, compatible with eelgrass, for use in oyster and clam bottom culture.

a) Restoration and expansion of eelgrass meadows (Zostera marina)

Recent field testing in Pacific Coast estuaries similar to Willapa Bay found that the transplantation of Z. marina eelgrass in beds with high concentrations of shrimp effectively decreases shrimp population to levels acceptable to both on-bottom and off-bottom oyster culture (Castorani et al. 2014). The dense root mass (rhizome) of eelgrass meadows creates a natural tough surface barrier, making it difficult for shrimp to reach the surface. Access to the surface is necessary for certain life cycle functions. In addition, shrimp are more vulnerable to predation at the surface from predators living in eelgrass ecosystem communities. Therefore, shrimp are typically found in significant numbers on the edges of eelgrass beds, or in pockets that become free of eelgrass.

Unfortunately, oyster dredging can temporarily or permanently remove eelgrass rhyzomes, making it more likely that shrimp will colonize and infest the new bare ground. Further development of the Multi-tasking Oyster Harvester would therefore logically incorporate the ability to perform shellfish farming operations within eelgrass meadows, as described later.

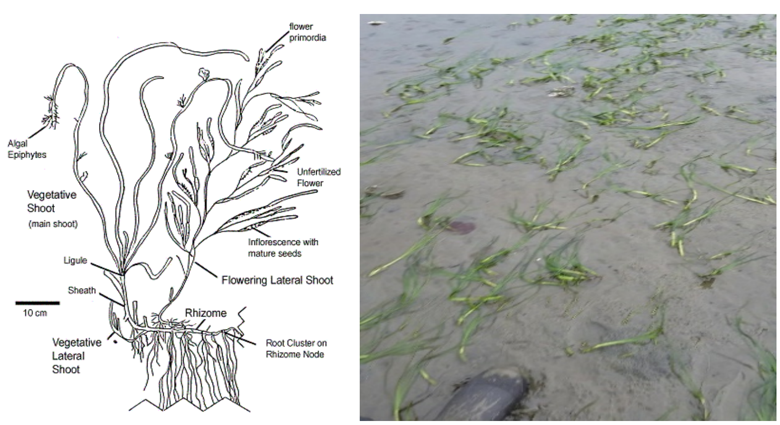


Figure 9 Eelgrass illustration (*Z.Marina*) and Willapa Bay eelgrass bed

b) Installation of shrimp blocking biodegradable bed mat barriers

It has been shown by field testing and anecdotally in current commercial shellfish operations that burrowing ghost shrimp populations can be controlled by the application of biodegradable open weave geotextile mats and geosynthetic mats. This may be done by laying a biodegradable open weave mat on or slightly below the sediment surface that would provide a barrier for adult shrimp, but would allow water and other organisms to pass through. It is thought that most of the decrease in shrimp is by lateral evacuation, that some do not survive and that some remain. Field testing with biodegradable open weave geotextile mats and commercial uses using geosynthetic mats found shrimp population decrease to levels acceptable to shellfish farming (Castorani et al. 2014)

The mat could also be seeded with eelgrass rhizomes and/or seeds to quicken and enhance ground stabilization. This is recommended for "lost ground", i.e. ground that has been suitable but due to high ghost shrimp populations is now deemed unsuitable for either on-bottom or off-bottom oyster culture. The mat would either be seeded with eelgrass rhizomes-roots or the rhizomes-roots would be transplanted before or after the mats are placed. The mats would then be either "frosted" with sediment or topped by normal sediment flow. When the mat decomposes the eelgrass will continue to discourage the return of the shrimp, and if farming methods are employed that do not eliminate the eelgrass, the bed should be sustainable.

Current Research and Trials
Similar methods of burrowing shrimp control are being studied and deployed in Puget Sound for clam aquaculture. Research and test trial information was acquired from Puget Sound Restoration Fund (PSRF). Current practices were discussed as noted below.

Current Practice
Barrier treatment to control ghost shrimp in Puget Sound has been done for at least two years for manila clam beds. A non-biodegradable geotextile material with a tight weave (said to be similar to that used in road construction) is placed on the clam bed prior and then the bed is "frosted" with 4-5 inches of gravel. Apparently, this effectively controls burrowing shrimp, but other organisms cannot pass through the mat/gravel barrier and a hypoxic layer forms above and below the barrier.

The mats used were non-biodegradable geosynthetic polymer fabrics used primarily to facilitate filtration and water drainage through soils without the loss of soil particles; to provide separation between dissimilar materials; and also provide a stable platform over soft or wet soils to facilitate the movement of equipment. (Note: Geosynthetic mats are also used in landscaping applications for long term erosion control, but manufacturers state that they should not be used in wetlands or environmentally sensitive areas.)

Research and Near-Term Application

Puget Sound Restoration Fund (PSRF) has been working with the Skokomish Indian Tribe to test shrimp control barrier treatments for clam beds. Open weave Coir (coconut fiber) mats of various weights and weave openings frosted with gravel were tested on ground with ghost shrimp populations. The field testing was deemed a success - shrimp were excluded from under the test mats, there was no sign of hypoxia and the mats showed little to no sign of degradation in the 1 ½ years of testing. That it did not degrade quickly was a success, as they are looking for semi- long-term shrimp control.

Application on a commercial Skokomish Indian Tribe clam bed is planned for September 2019. Coir mat will be used with a 5-inch gravel topping. Mesh size is not known.

Current Recommendation Concept

We suggest studying the use of open weave biodegradable geotextiles laid directly on top of or slightly (pressed) under (lost) ground. A 2+ inch layer of sediment would be placed atop the mat. We also suggest a study of the feasibility of attaching eelgrass rhizomes and/or seeds to the mats in order to accelerate the densification/stabilization of the sediment. Ease of attachment would likely be a function of type of material and size of mesh. Open weave fabric materials might include coconut fiber, composite fiber of coconut open weave with coconut mesh fiber, jute (burlap), wood fiber and wheat straw. The life expectancy of such materials ranges respectively from 6 years to 6 months.

Other items and variables that need to be further investigated:

- Types of mat materials
- Placement and attachment methods
- Time needed to effectively control shrimp population vs shrimp density (and the accompanying necessary life of mat fabric used)
- Cost of large-scale mats, materials, installation and maintenance
- Optimum open weave (mesh) size

Figure 10 Biodegradable Coir bed matt

For more details please see the **Technical Details of Mechanical Concepts** section.

Objective 3:

Improving shellfish farming operations and productivity

Develop mechanical devices and operational methods that improve commercial productivity through innovation in culture methods, harvesting equipment, and handling techniques.

Goals:

- reduced cost of production, labor, and energy
- greater flexibility in harvest and cannery operations
- shrimp control as a by-product of other normal operations

a) Multi-tasking Shellfish Harvesters for operation over eelgrass

We strongly recommend further development of the Multi-tasking Oyster Harvester, and Clam Harvester (shown previously), to be compatible with operation in eelgrass. We did not have sufficient time to fully explore mechanical and biological issues, such as rhizome pull-out resistance, and rhizome recovery following various levels of sediment disturbance. These tasks, and others, would need to be clearly defined and studied following successful proof-of-concepts on the first new harvesters.

b) *New Bateaux* and Mobile Multi-tasking shellfish harvesters

Multi-tasking Shellfish harvesters would first be used on existing scows and workboats. However, it may be worthwhile to consider what type of new workboats would be best suited to improving productivity on other aspects of shellfish operations, such as other harvester operations, lifting and cleaning the product, transportation to and off-loading at the cannery. In addition, growers pointed out that “high” clam and oyster beds are too shallow for traditional dredge harvesting. Therefore, these beds must be harvested by hand, which although more selective in picking quality, and less harmful to eelgrass, is, nonetheless significantly more expensive.

First insight

With these requirements in mind we first looked at using a portion of the eductor waterpower to perform other processing functions typical of other eductor systems, such as gold dredges, debris separation, and ocean mining operations.

We believe labor-saving features could be added to the Multi-tasking shellfish harvesters previously mentioned. The new tasks could include:

a. Breaking-up and separating oyster clumps
b. Cleaning and sorting the product into sizes

c. Transferring the product from the beds to the work scow via the existing eductor powered large diameter hose.

Second insight
A second insight considers what to do with the harvested product once it is educted to the work scow. Traditional dredges and scows carry product on the deck. Typical maximum capacities are in the 1000 to 2000-bushel range. Because oysters and clams have a specific density of approximately 1.2, the weight the scow carries could be reduced by as much as 50% if the product was carried submerged. Therefore, a smaller scow could be used for current capacities, or more capacity could be carried "flooded" by a typically sized or slightly larger "***New Bateaux***" (See Figure 11).

In addition, the *New Bateaux* could be fitted with containers suitable for lifting and onloading directly into the cannery. In this way the product stays alive in the *New Bateaux* or other cannery tank or container, until ready to be lifted out for processing. Figure 11 illustrates one possible New *Bateaux concept*, for either a powered scow with pilothouse, or unpowered scow-barge.

Third insight
A third insight considers using some portion of the eductor waterpower to move the Multi-tasking shellfish harvesters, independent of the scow or *New Bateaux*.

Traditional oyster dredges, including the proposed Multi-tasking harvesters, are propelled by towing cable(s) from the dredge scow. Therefore, the dredge basket can only operate in water deep enough for the dredge scow; limiting not only the acreage that can be mechanically harvested, but also the towing pattern that can be covered, and the time available to harvest owing to the rate of tidal change.

We now envision modifications that could allow the crew to steer and position an eductor powered Mobile Multi-tasking shellfish harvester into shallower water while the scow or *New Bateaux* stands in deeper water. We were time limited in further developing this concept's engineering details. However, to date we have found no fatal flaws in the basic device concept. However, we have yet to discuss the value of the Third Insight with the growers.

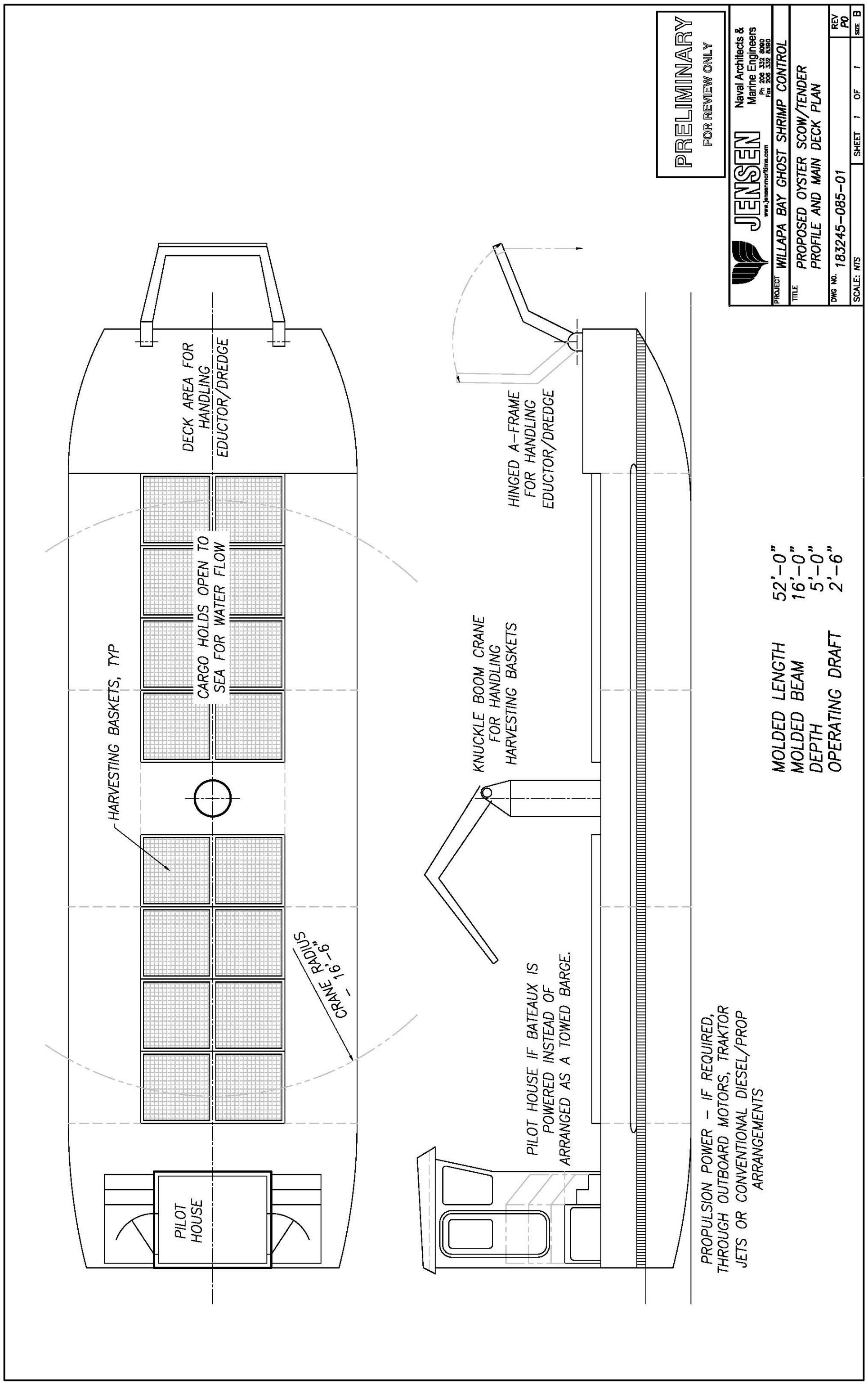


Figure 11 Griffin Team New Bateaux for Mobile Multi-tasking shellfish harvesters

c) Off Bottom technology

Suspended Oyster Culture in Willapa Bay

Some suspended oyster culture takes place in Willapa Bay for the higher priced single oyster grown for the restaurant markets. The methods and techniques encompass the spectrum of oyster bags suspended from surface floats to systems that suspend the oysters off bottom using stakes. Many of these techniques are used worldwide in a variety of similar configurations.

In Willapa Bay these techniques have been employed to

- Produce a higher valued oyster to meet consumer preferences
- To prolong the use of ground softened by ghost shrimp that eventually renders on bottom oyster culture unworkable.

Off bottom oyster culture may be the future of oyster culture in Willapa Bay, but the effect of off bottom culture in the long term is still unclear. For example, the off-bottom culture is intensive in its use of plastics and the scale and number of the floats and oyster containers is so great that we *might* expect the numerous farms to alter the natural flow of water, sediment and fauna in the bay. Floating and staked oyster culture does nothing to stop the ghost shrimp infestation on the sediment below the suspended culture. On the other hand, if lost ground is conditioned and reclaimed by eel grass suspended culture might be an alternative to harvesting oysters with dredges on the same reclaimed ground.

Several initial ideas are shown below in Figures 12 and 13.

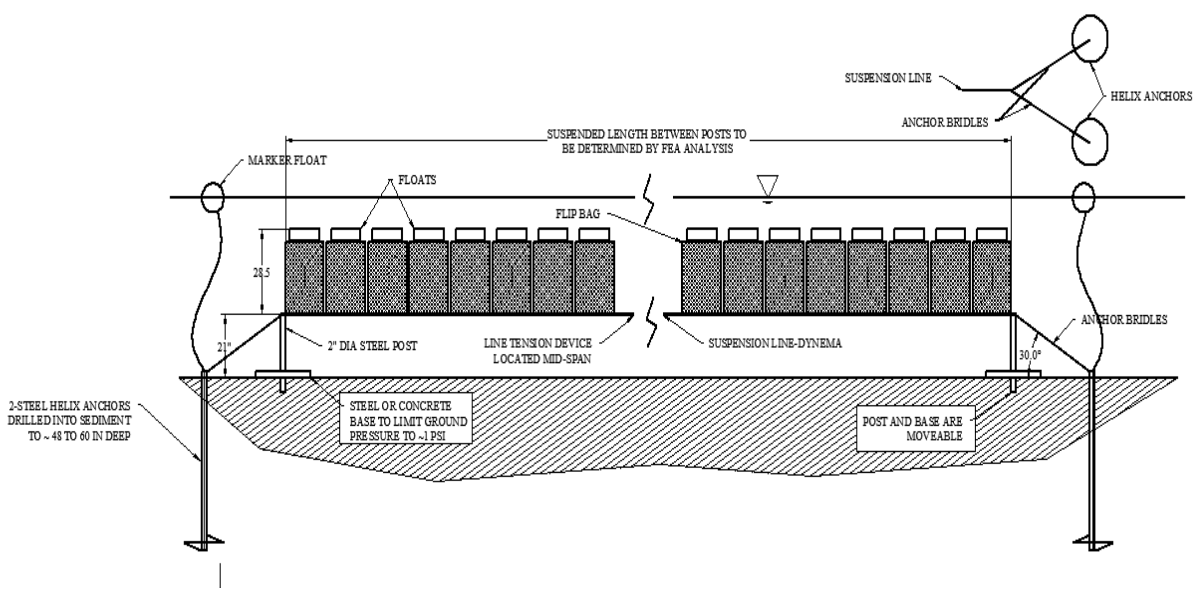


Figure 12 High tension flip bag system

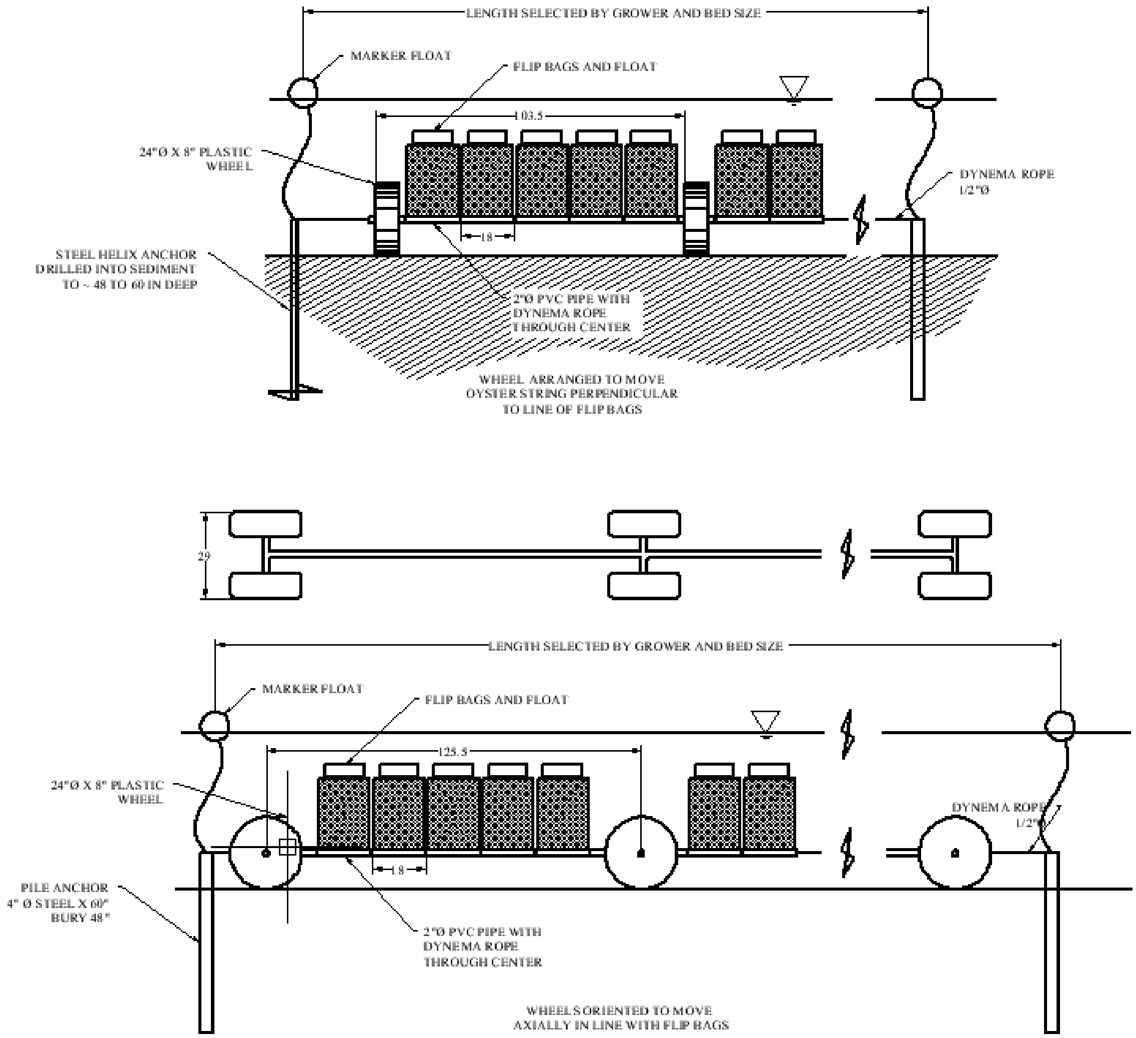


Figure 13 Use of wheels to support flip bag system

Objective 4:

Creating jobs

Advanced technology and mechanization are beginning to be used in canneries, and to some extent in basic farming operations. Can more be done to create and maintain good high paying local jobs to develop and support new technology within an industry constrained by nature, availability of labor, commercial markets, and other uncertainties?

Our group has witnessed time and again the primary role advances in marine technology play in maintaining commercial viability. It is well known that technology reduces production costs. What is not so well known is that technical development feeds on itself once a climate of innovation is created. This is what we hope for Willapa Bay and Grays Harbor- that local innovation, technology, and investment will emerge to help solve the current shrimp infestation problem, and lead to greater confidence and capabilities in addressing and benefitting from future problems and opportunities.

Consider the following advantages of just the simple things we propose in this report:

Goals:

- reduced cost of production, labor, and energy;
- greater flexibility in harvest and cannery operations;
- improved sediment and eelgrass health;
- shrimp control as a by-product of other operations;
- long-term access to "home grown" innovation and skilled labor.

a) Investment in local design, fabrication, and testing of recommendations.
Find ways to aid the ability for local folks to design, refine, and build on promising recommendations. Support is needed for new ideas that will likely emerge, including funding of start-ups and grower efforts to find mechanical solutions to commercial issues.

b) Investment in vocational training in new technology
Investment in vocational training at the high school level and beyond is well established in many communities. Special Agricultural, Aquacultural, and Vocational schools are training next generation workers in many areas. We would highly recommend that Washington State, Pacific and Grays Harbor Counties create one or more schools focusing on fisheries and aquaculture, and that industry groups like WGHOGA sponsor "real world" design challenges and prizes to encourage innovation and familiarity with the industry.

c) **Investment in early technical education, problem solving and design challenges.** Early education is moving toward innovation based "design thinking", not only for technical problem solving, but for problem solving in general. The main change is toward more open ended and inclusive group methods of brainstorming and discussion. In addition, it is helpful to focus on solving real problems, often with a skilled mentor assisting the teacher. Inclusiveness of all ideas gives value to initial "crazy" ideas that in the old days might be discouraged. Crazy ideas often lead to unique, beautiful and elegant solutions when supported to completion.

Solving of complex and open-ended problems, such as the shrimp non-chemical control initiative, or other local community problems, can be turned into community "opportunities", or in other words, the "blessing in disguise". We encourage and support any efforts to develop this style of brainstorming and innovation in local schools.

See examples from the Stanford Design school here:

https://dschool-old.stanford.edu/groups/k12/wiki/956b6/Design_Thinking_Projects_and_Challenges.html

Aquaculture Design challenge

Industry and non-profit *Design Challenges* at the high school and college level are increasingly popular ways of engaging students and schools in both technical development and athletic-type competitions.

For example, we would love to see inter-school competitions among local high schools, sponsored by WGHOGA and other State and local stakeholders offering funding for materials and prizes, to develop shellfish technology, such as an oyster clump breaker, or oyster sorter or opener.

See following for a few examples:
https://agfundernews.com/aquaculture-startups-dominate-finals-of-sustainable-seafood-business-competition-fish-2-0.html
https://www.asme.org/conferences-events/competitions

https://www.nasa.gov/offices/education/centers/kennedy/technology/lunabotics.html

Figure 14 Willapa Bay students studying robotics - Chinook Observer

Figure 15 Aquaculture high school - Bridgeport, Connecticut

https://www.bridgeportedu.net/domain/2958

For greater details please see: Looking Forward – Education and Training - Page 89

Objective 5:

Preparing for the future

The future of shellfish farming in Willapa Bay and Grays Harbor is not isolated from local and global environmental change. We recommend immediate stakeholder participation in becoming aware and prepared for emerging uncertainties. Specific details are shown in the **Looking Forward – Climate Change and Ecosystem Details** section.

Goals:

- Ability to adapt to short-term local ecosystem changes
- Ability to plan for longer-term external environmental influences
- Greater certainty in making commercial investment in current and new farming infrastructure, equipment, and talent.
- Ability to contribute to and learn from other shellfish stakeholders worldwide

a) Wide area and fine granulation monitoring of shellfish ecosystems

Survival of the local shellfish industry will more than likely require detailed and long - term monitoring of the specifics of the Willapa Bay and Grays Harbor estuaries, including oceanic near-shore and far-shore conditions. Willapa Bay and Grays Harbor are unique ecosystems, unlike any others in Washington State and along the West Coast. Preparing for changes in ocean temperature, acidification, availability of required phytoplanktonic food sources, and other emerging variables could have a significant effect on decisions farmers, stakeholders, and policy makers need to make well in advance (See Figure 16). Regular headlights are not enough. The industry will need super high beams and multiple drivers to stay on the road.

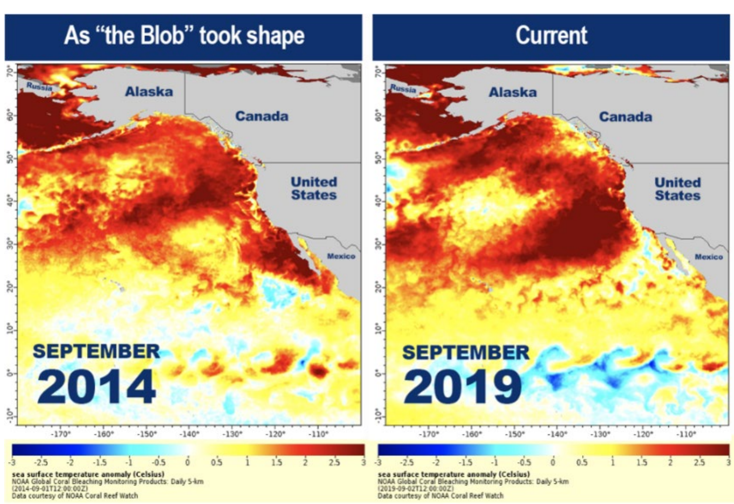


Figure 16 The current thermal Blob off the Washington coast https://www.forbes.com/sites/allenelizabeth/2019/09/05/another-warm-blob-is-forming-in-the-pacific-ocean/

b) Technical and policy collaboration.
Leadership is needed to create and fund open continuous collaboration among local, regional, and global shellfish growers, scientists, industry and governance. However, talk is not enough. Therefore, we recommend the development and funding of commercially focused projects among Pacific Rim stakeholders; private and public. The choice of projects should be peer-reviewed and selected only on their direct applicability to all parties and regions.

We likewise recommend similar collaboration on matters of policy and governance.

c) Development of a Coastal Shellfish Incubator
We strongly recommend that Washington State, DNR, the WGHOGA Growers Association, and private-public funds be used to develop a Coastal Shellfish Incubator facility in Southwest Washington. This facility would be available at zero to low cost for start-ups, entrepreneurs, and small companies engaged in commercial proof-of-concept exploration of alternative culture methods, strategies for mitigating climate change, shellfish industry productivity, value-added products, and related business.

Currently there are no incubators, accelerators, or start-ups listed on the Washington Coast by Washington State Dept, of Commerce. Most are found in heavily populated areas (https://batchgeo.com/map/57587e8fec06e95892b67d3dc96261b9).

Although many examples exist on which to model the effort, we believe the State should take a fresh look at ways to create commercial development labs in agricultural, underserved and low population areas. Like politics, all innovation is local.

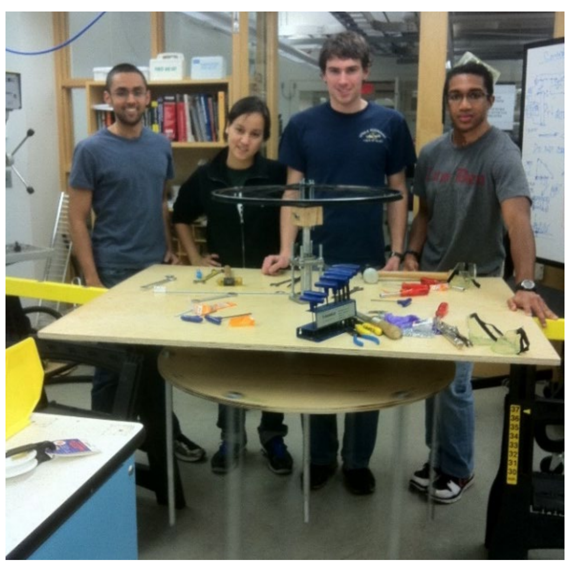


Figure 17 Low speed deep-ocean electric generator model in design incubator - 2011

4.3 Recommended priorities

We recommend that DNR and the PWG consider the following order of action. This approach will create the greatest synergy, produce the fastest results, and achieve the best forward-looking outcomes.

#1 priority --- Looking Forward- Climate and Ecosystem Action

Ecosystem revival and preparation for climate change

- Preparation requires that long-term monitoring begin as soon as possible to inform technical/political collaborations and decisions.
- Ecosystem rehabilitation improves community health and commercial resilience.
- Promising new shellfish farming methods are emerging in the US and globally.

2 priority --- Multi-tasking oyster and clam harvesters

Develop tools and techniques that inhibit or remove juvenile shrimp in the upper sediment from all productive, fallow, or lost ground

- 1000 female shrimp can produce 4 million or more swimming larvae each year.
- Larval shrimp settle and colonize wherever favorable sediment occurs in the estuary.
- Young shrimp live at least one year in the upper few inches of the sediment.

3 priority --- Bed tools such as chain and pulse trawls, rollers, and eductors

Develop tools and techniques that recover "lost ground" and other marginal land

- Formerly productive shellfish beds with large adult shrimp are called "lost ground".
- Lost ground produces large numbers of larva.
- Lost ground can be favorable to young shrimp

#4 priority --- Multi-tasking on-bottom harvesters compatible with eelgrass

Develop multi-tasking shellfish harvesters and bed tools to work within eelgrass meadows. Develop efficient methods of planting, restoring, and managing eelgrass ecosystems.

- Eelgrass plays the primary biological role in stabilizing Washington State coastal estuaries.
- Eelgrass provides protection for shrimp predators.
- Eelgrass roots inhibit the growth and development of burrowing ghost shrimp.
- Oyster dredging, harrowing, and mowing can temporarily or permanently destroy eelgrass beds. 60% of commercial Willapa Bay shellfish tidelands are dredged and harrowed.

5 priority --- Multi-tasking workboats to improve farming productivity

Develop harvesting and techniques that reduce labor and production costs; allow mechanical harvesting in shallow water operation, and improve product value

- Each time a hand touches shellfish it adds to commercial costs.
- Shellfish farming in areas inaccessible to dredging must be done by hand.
- Off-bottom methods are labor intensive and obstruct the natural sediment/water interface
- Shellfish value reduces in proportion to time out of water.
- Community based innovation and technical support cannot be developed overnight.

(end of Summary of Concepts and Recommendations)

5. Technical Details of Mechanical Concepts

Introduction

The following section of **Technical Details of Mechanical Concepts provides** additional details to concepts not fully presented in the **Summary of Concepts and Recommendations** section.

Contents

Harvesting and Bed Conditioning Tools – Technical details

5.1 Multi-tasking oyster harvester (Ref. Figure 18)

Based on our present understanding of the problems and constraints cited in our introduction the most plausible, practical and immediately workable mechanical solution involves a redesign of the oyster dredge and the introduction of a new design for clam harvesting system. By continually using this type of dredge the population of adult shrimp will slowly be reduced and the settling of small shrimp and recruits will continually be disrupted. It should be stated that these designs shown in this document are conceptual and not yet comprehensive, but rather should serve as a basis for later detailed work and proof of concept.

The towing of oyster dredges to move or harvest oysters is a common activity by the growers throughout the year. We propose to redesign the dredge to not only capture oysters but at the same time to condition the sediment so that that extra small shrimp and the shrimp recruits are killed or maimed in the process. This redesign will have the benefit of eliminating any extra costly and time-consuming operations over the bed to condition the sediment. In this regard the dredge becomes not only an oyster harvester but also a multi-tasking tool, accomplishing more than one action at a time.

The means and justification to accomplish the multi-tasking harvesters are detailed in the following sections. The multi-tasking harvesters are imagined employing one or more of the following features which will allow the harvester to condition the sediment, ie, kill any shrimp that comes within the mouth of the harvester or ends up underneath it. These features include the following:

1. A box like harvester with opening at the front and back ends.
    a. Enclosed sides and top.
    b. Towed at 2 to 3 kts it will have natural water flow through the box like structure forcing large oyster clumps and single oysters into the catch bag.
    c. Opening into the mouth and interior chamber will be large enough to pass the largest oyster clumps.
    d. Initially the width of the harvester should be no larger than contemporary dredges. Which is on the order of 5 to 6 ft.
        i. At 3 kts (5.04 ft/sec) a single harvester would cover about 0.50 acres/hr.
    e. The leading edge of the scoop should be rounded to reduce disturbance of eel grass.
2. A chain, tines or toggled harrow in front of the harvester.
    a. To tumble partially buried oysters to the surface
    b. To break up clumped oysters
    c. To turn up any shrimp that are near the surface of the sediment
3. A depressor wing located in the mouth of the harvester
    a. To stabilize the harvester and force it to the bottom
    b. To direct flow upward into the mouth of the harvester.
        i. To help lift oysters into the harvester
        ii. To direct neutrally buoyant shrimp into a capture or kill area
4. An eductor located behind the wing
    a. To increase the flow of water and oysters into the harvester
    b. To direct neutrally buoyant shrimp and lighter sediment to kill/capture area in the harvester
    c. Eductors have the capacity to lift the oysters to the surface, but that should be left to later design evolutions because it requires a more complicated system.
    d. Other means such as a powered flettner rotor could also be used.
    e. The enhanced flow caused by the eductor will create a slight vacuum pressure on the surface of the sediment helping to lift oysters and sediment, as well as shrimp.
5. Below or behind the harvester a pulsed electrical array that slides along the sediment.
    a. An existing technology redesigned specifically to kill or maim any shrimp within the electric field.
    b. This technology might also be used in the kill area of the harvester.
6. This harvester would be longer and heavier than those presently used in Willapa Bay.

   a. Initially it needs to be designed within the towing and lifting capabilities of the existing oyster scows
   b. As the technology is proven and economies of scale are applied it is reasonable to think the oyster scows themselves will evolve for efficiency and handling.
7. This type of harvester could be designed to test the various technologies in stages. With adequate funding and professional engineering input it could be fully tested with a year.

The figure 18 shows an embodiment of the ideas stated above. It is not an endorsement of this particular design, but rather a starting point for understanding the concepts put forward. However, the concept as presented is a workable and economical mechanical solution for on bottom oyster culture.

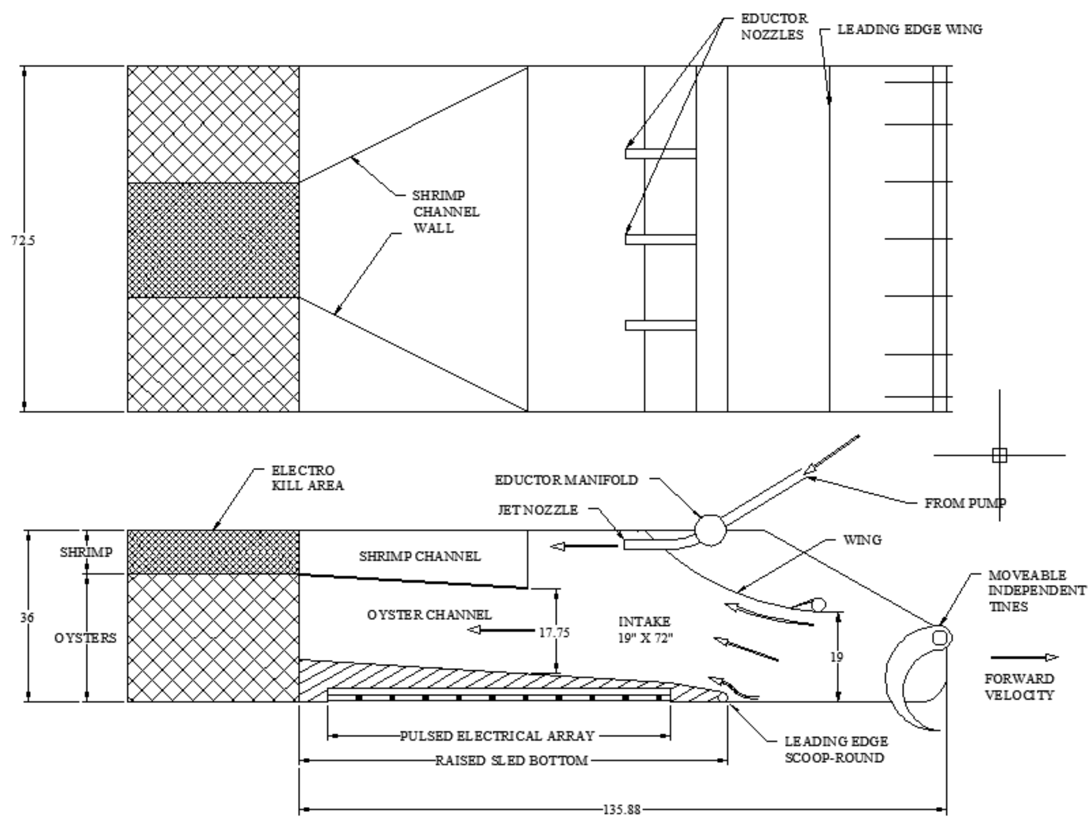


Figure 18 A conceptual multi-tasking oyster harvester redesigned.

5.2 Multi-tasking clam harvester (Ref Figure 19)

There are several different ways that clams are harvest mechanically. In some cases, clam ground is periodically “frosted” with gravel. After time the gravel layer becomes 4 to 6” deep and possibly greater. The manila clams establish themselves at a depth of 2 to 3 inches within the gravel. As an alternative to other techniques of harvest we propose the following harvester that could harvest clams as well as condition the soil by eliminating juvenile ghost shrimp:

1. A box like harvester with a large opening at the back where clams and gravel can be separated
    a. A grid work retaining large clams and allowing gravel and small clams to fall to the bottom.
    b. The tow velocity across the bottom will be a function of the suction capacity of the eductor.
        i. Initially it might be designed to move at a speed of 0.5 knots (0.84 ft/sec)
    c. The width of the harvester initially would be on the order of 3 ft. giving 4.73 hrs to cover an acre.
2. An eductor suction head that lifts a slurry of gravel, sediment and clams into the harvester along with any shrimp that may reside in the same gravel layer.
    a. Part of the eductor flow would be used to agitate or wash the gravel and clam mixture.
    b. The motive force for the eductor could be on the harvester or surface supplied
3. The electro-pulse array could be positioned at the bottom of the harvester to kill any shrimp within range of the electric field.
    a. Inside the harvester an additional electro pulse array would kill any shrimp caught in the slurry as it flows through the harvester.
4. The clams would accumulate in a bag similar to that used by the oyster harvesters so they would be periodically lifted to retrieve the clams.
    a. The eductor flow would be capable of lifting the slurry to the surface or perhaps lifting after the gravel and small clams are put back onto the beds.
        i. Initially this is a complicating factor that should be left to future developments.
5. This type of harvester could be designed to test the various technologies in stages. With adequate funding and professional engineering input it could be fully tested with a year.
    a. Some of the testing and design would also result from of the new oyster harvester development.

Figure 19 shows an embodiment of the ideas stated above. It is not an endorsement of this particular design, but rather a starting point for understanding the concepts put forward. However, the concept as presented is a workable and economical mechanical solution for clam culture in Willapa Bay.

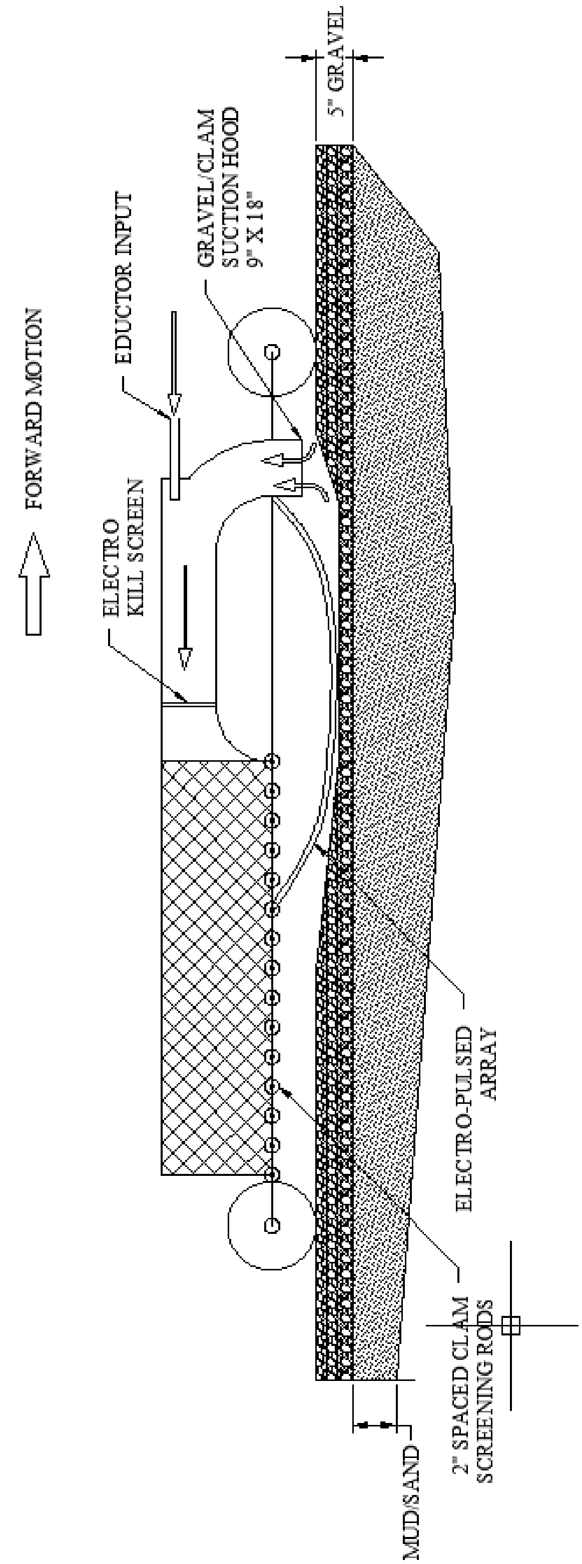


Figure 19 A new conceptual multi-tasking clam harvester

5.3 Wet and dry bed rollers

Rolling on exposed tideland (dryrolling) has shown to eject shrimp from their burrows. When rolling over inter-tidal sediment in the submerged case (wet rolling) the results may be different because the pressure wave in front of the roller might be expected to be longer than in the dry rolling case. Wet rolling would require a submerged roller towed over the shellfish beds by a vessel or a winch mounted on an anchored vessel. The best roller weight and speed across submerged sediment will still need to be determined.

Mechanical basis for shrimp control using rolling devices

Ghost shrimp burrows in tidelands liquify the soil above their burrows and thus reduce the ability of the sediments to support weight. Oysters and other surface objects will sink and suffocate not only by their own weight, but also by tidal and wave forces. Wave induced motions (both lateral and vertical) of the oysters resting on the soft sediments may cause oysters to become buried as wave motions impart changes in the pore pressure between sand/mud particles. Pore pressure changes would likely cause cyclical micro-liquefaction adjacent to the oysters; increasing the likelihood of further sinking. This difference in pore pressure (which can cause temporary liquefaction) is caused by wave action as shown in Figure 20.

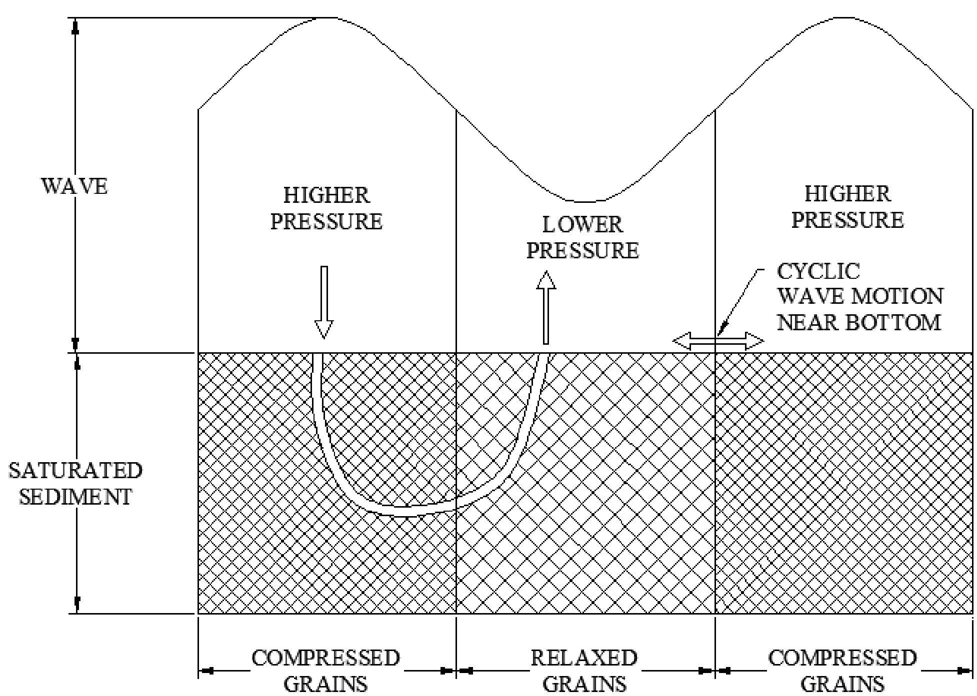


Figure 20 Water wave cycling that cause soil liquefaction

Any induced pressure change, whether mechanical or natural, that increases the pore pressure cause water to flow within the soil as the pressure increased or decreased. In the case of shrimp infested tidelands, the burrows which are open to the sediment surface represent voids to which pore water trapped in sediment can quickly flow into as the result of mechanical pressure as shown by the arrows in the Figure 20.

Some experience ejecting shrimp out of their burrows on exposed intertidal bed while using large rollers has been successful in theory because the pore water flows into the burrows easier than the surrounding sediment. This action ejects the shrimp to the surface of the sediment where they can be captured or killed. In the event the shrimp is not ejected the burrow still collapses and might crush or maim the shrimp. We might assume that the shrimp are ejected in front of the roller as it passes over the tidelands, but that has yet to be determined.

Simplified sponge test

A simplified experiment to test the plausibility of the ejection theory was conducted as part of our work. The test consisted of a sheet of open cell foam or sponge with burrow holes punched in the foam. Small beads were inserted in the holes with the sponge saturated with water. A paint roller compressed the sponge while at the same time moving from one end of the test bed to the other. The beads were ejected from the sponge. No attempt was made to adequately scale the sponge or burrows or beads to generate a more perfect engineering model, but the test did demonstrate plausibility of induced pressure uses in both dry and wet rolling designs and strategies. Figure 21 shows the set up.

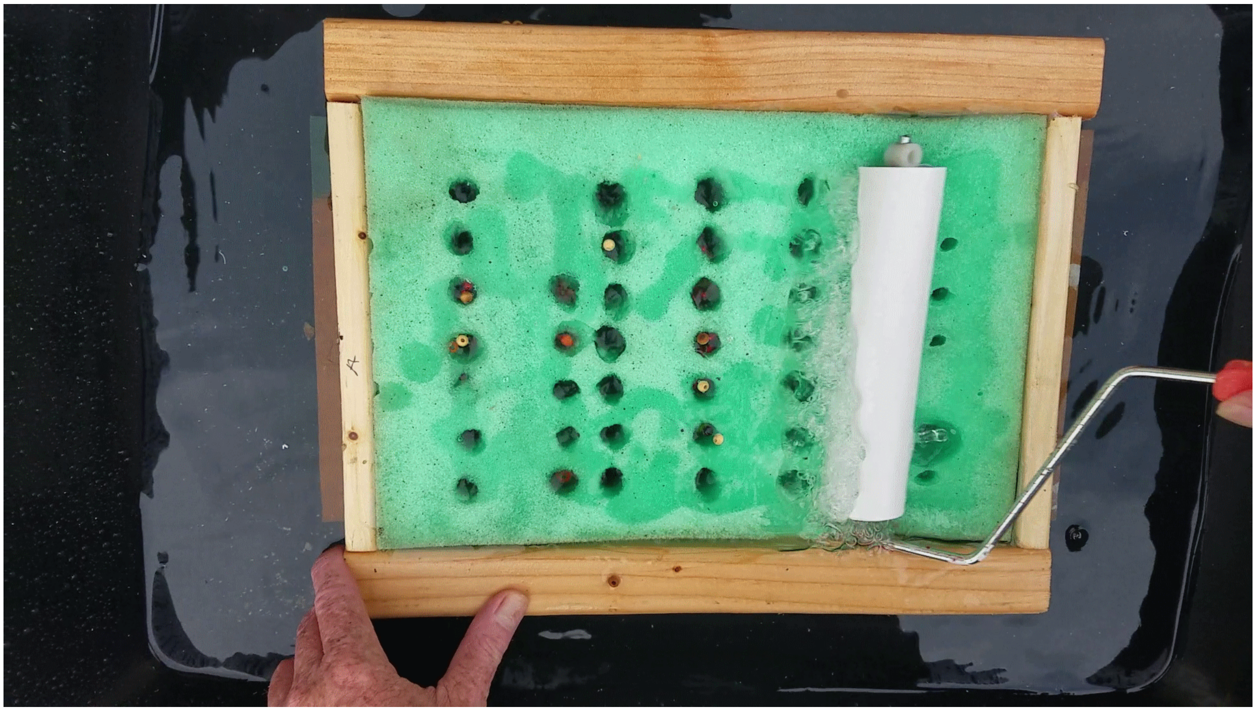


Figure 21 Sponge test of "shrimp" ejection

DNR Marsh Master roller tests – Bay Center, July 2019

The Marsh Master (MM) vehicle was used on Bay Center grounds that were devoid of oysters and relatively packed sandy sediment. There was little if any tendency for observers to sink while standing or walking on sediment. The MM has a tread length of approximately 81 inches that rests on the ground. Traveling at 6 mph means the tread moves (relative to the vehicle) at about 8.8 ft/sec with the entire tread along its length passing a particular point on the sediment in about 0.76 sec. and leaving two tracks of depressed soil behind. Sometimes a wave of sediment pushed up ahead of the tracks is visible depending upon the initial density of the soil.

The observation on the first test site showed the MM was ejecting adult female shrimp from their burrows and on a second later pass over the same ground a greater percentage adult male shrimp. The second test plot had a denser sediment and fewer shrimp were ejected although there was a greater percentage of adult males. In the cases of both test plot we observed that the drum of the roller did not maintain contact with sediment but was raised up and rotated on its tines. This led to the conclusion that it was the weight of the MM acting on the sediment through its treads that was ejecting the shrimp out of the burrows.

The effect of the tines in regard to ejection of the shrimp was not at all apparent. Because of the speed of the MM (~6 mph) and the spray we were not able to photograph the exact time or mechanics of shrimp being ejected from their burrows, but we could only observe the shrimp left on the ground after the MM and roller passed. It should be noted that most of the shrimp in the tread paths appeared to be un-harmed and fully functional. How this is possible is still speculative. Perhaps the MM treads pushed them up in their burrows high enough the tines were able to turn them to the surface? A photo of the MM and roller is shown in Figure 22.

Figure 22 Note the roller drum is not in contact with the sediment.

Of particular interest is the fact that the MM and roller shown in Figure 22 is capable of treating about 4.5 acres per hour. It appears that the MM is capable of towing a wider roller and possibly tandem rollers to cover the same area in less time and with a single pass rather than the two passes during this test. It is possible that the tines on the roller can be eliminated with improvement to the entire operation.

Potential benefits of wet rolling

We believe that using rollers on the tidelands when the tide is in may have additional advantages when compared to dry rolling as long as oysters are not present on the bed and/or when used on growing ground already completely lost to shrimp infestation. Capture, maiming, and killing devices could be added to the basic rolling mechanisms. This would include the following:

1. When towed by a floating vessel there is little possibility that the vessel will find itself mired in the soft sediment and thus need to be pulled out.
    a. Heavier land vehicles can become unstable should a single track or wheel liquefy the soil beneath the treads.
    b. Traction can be reduced or lost due to liquifaction beneath the treads.
    c. Although vessel propellers are not as efficient as land traction vehicles as long as the prop has sufficient water its pulling power is not affected by the nature of the seabed.
2. Being able to work when the tidelands are covered with water will give a wider time window for rolling the lost beds if that proves necessary.
    a. This is especially true for those oyster beds that are in deep water where the tide window for working the dry ground is short.
    b. Since high tides are generally during the day in the winter vessels working rollers on their beds will be able to work during the daylight hours.
    c. Wet rolling may prevent channeling of the bed as water under the influence of gravity will not flow from high ground to low ground as in Figure 26.
3. It is thought there will be reduced damage to eel grass with wet rolling using smooth rollers rather than toothed rollers.
    a. Ground lost to shrimp infestation rarely has significant eel grass
    b. Wet rolling may cause minimal damage to eel grass rhizomes if appropriately designed following prototype testing.
4. Wet rolling can initially be accomplished with the vessels that the oyster growers use daily to tend their beds negating the necessity to spend additional capital on tractors or amphibious vehicle required to tow the rollers on the dry tidelands.
    a. If wet rolling is a successful strategy specially designed vessels for rolling might evolve with experience.
    b. Vessels of opportunity can usually be chartered for such operations
    c. When not used in oyster operations the same scows might be chartered for wet rolling.
5. There are a number of configurations for the roller which might better force shrimp out of burrows other than a smooth roller.
    a. See Figure 27.
6. In order to efficiently condition the beds by removing adult and juvenile shrimp it is plausible to combine a harvester and a trailing roller so that the growers do not have to harvest and condition workable ground in separate operations
    a. For efficiency a new harvester/roller design for operating on existing oyster beds is the most promising for success.
    b. In this case the harvester would remove most or all of the oysters in the path of the roller reducing the possibility that the roller would bury or break up oysters.

Preliminary design discussion

Since the previous trials with the dry rollers has had some good success at ejecting shrimp from their burrows it is logical to develop rollers similar to those used in the 1960's or the same roller/chopper used in the POC but use them for the wet trials. Some of the primary considerations for design include:

1. The design of the roller itself, size, weight, toothed or smooth
    a. Fixed cylinder or rolling cylinder
    b. Simplified non-rotating heavy steel weight
2. The carriage designs
3. The required power to pull the roller
    a. Ground friction
    b. Hydro-dynamic drag
    c. Towing warp scope ratio, buoyancy, and drag will require that the roller/weight be heavier than the one used for the POC.
4. Determination of success or failure in ejecting shrimp
    a. Provisions for camera observations
    b. Capture net or mechanism for shrimp behind roller

Power requirement for wet rolling

The paper "*The contact drag of towed demersal fishing gear components*" (F.G.O'Neill, et al , https://doi.org/10.1016/j.jmarsys.2017.08.002) gives a detailed engineering study of the friction drag of various types of smooth trawl roller gear across the seafloor. Selected measured data from the test on finer sediment (D50 grain average of 85 µm) was used to predict power requirements.

1. Of particular interest is the 15.75" diameter x 24" long roller which has a water weight of 396 lbs. At 2.4 knots the total drag is approximately 183 lbs.
2. Under the same conditions 4 of these units side by side would measure 96" long and weight 1612 lbs and have a total drag of approximately 936 lbs.
3. Given the roller of item 2 above the ideal horsepower (force x velocity) to tow this 8 ft roller would be ~ 7 hp. Marine propulsion with about 20% efficiency would need to be in the range of 35 hp.
    a. Note-the weight of this roller is high compared to the standard trawl rollers used in the US and may represent the single clump weight used when towing multiple nets from a single pair of doors. It did work out nicely for our purposes since the POC roller study was also 16" diameter.
    b. For this power prediction the hydro-dynamic drag was about 180 lbs and a higher towing speed would change the drag and possibly the behavior of the roller, in particular its pressure and stability relative to the bottom.

Based on ONeill and the previous POC it is likely that some skiffs and certainly the larger scows could drag a single 8 ft wet roller for a test study.

The above cited paper also studied the same cylinder when it was restrained from rolling and in general found the contact drag to be ~ 3 x that of the rolling drag.

Test evaluations

A wet roller test (not combined with harvester) will require some means of determining the success or failure of a design to eject shrimp from the burrows. Although population density evaluations along the lines of those measured during the POC tests might be necessary other more immediate assessment might be to observe the dead or captured shrimp behind the roller during the actual tow. This would require cameras or divers for underwater observations or a towed trawl type net to collect shrimp. Figure 23 shows a generic roller and trawl type net. Figure 25 illustrates a heavy plate (cross section) being towed across the bottom instead of a roller. The July 2019 MM tests at Bay Center indicated that just the track pressure of the MM was enough to eject shrimp.

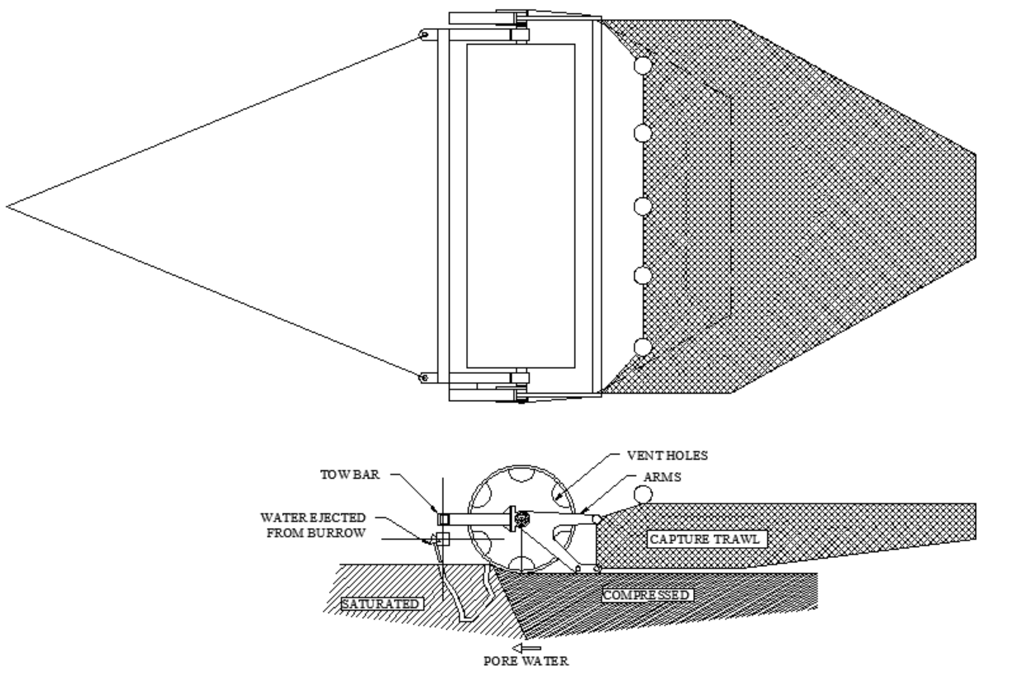


Figure 23 Roller with trawl type capture net

The real objective of the wet roller trial is to kill all shrimp ejected from their burrows, not capture them. For the dry rolling study once the shrimp are ejected, they remain on the ground influenced by gravity. In a water environment they will be more influenced by the flow of water around and behind the rotating cylinder since their buoyancy will negate gravity for the most part. Therefore, it is essential to have cameras stationed in front of and behind the roller for observation. At slower speeds fluid flow would not be enough to move shrimp, but at higher speeds shrimp ejected in front of the roller might actually go up over the top. As shown in Figure 24 there may need to be a provision for a kill bar behind the roller to damage or kill any shrimp on the sediment surface. This kill bar could be made of a stiff bristle brush or toothed metal disks which run over any shrimp on the surface.

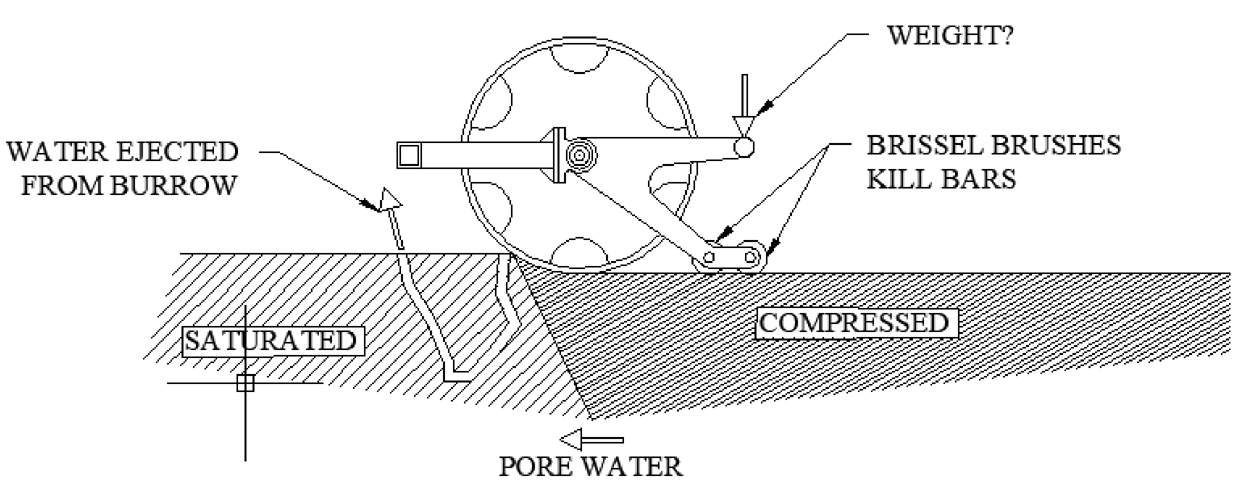


Figure 24 With kill bar in place of net

Other considerations concern whether or not the roller would actually slide in the soft sediment rather than roll and might require teeth welded full length or only on the ends to cause rotation.

It is also plausible that pressure is all that is needed, and rolling is not necessary. If, for example, power requirements are not a limiting factor a heavy weight could have the same effect on the ground pressure and the shrimp without the complexity of a roller, bearings and carriage. A generic cross section is shown in Figure 25. Here a slab of steel 12” wide x 6“ thick x 96 in long and shaped to the cross section shown would weight ~1712 lbs in water excluding rigging plate and other necessities. In this case the steel slab would have a contact pressure against the sediment of ~1.49 psi. (the Marsh Master is reported to have a ground pressure of ~1 psi and human standing on two feet experts a ground pressure on the order of 4 to 5 psi). A roller might have a higher pressure than the steel slab depending upon the contact area so this should be taken into account when sizing the slab. A roller may also experience less wear over the long run because friction with the sediment will be reduced.

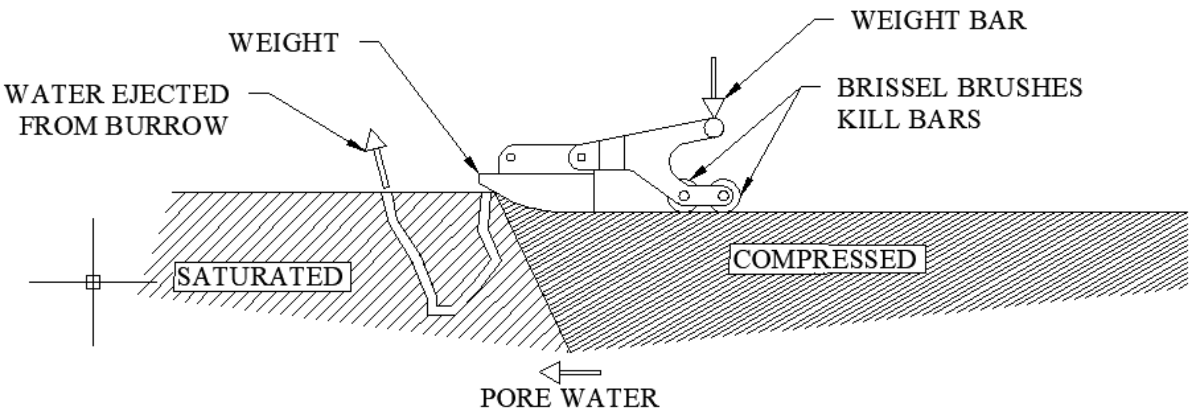


Figure 25 Steel slab fitted with kill bars

Interactions with other marine life

At 2.5 knots most adult crabs and fish can avoid the roller or the steel slab. It is not known how many large or small crabs might inhabit the inter-tidal zone but rolling the beds may not have any more effect on crabs than dredging for oysters. Smaller fish may get carried up over the roller by the water flow pattern, though whether or not small crab could avoid the roller is unknown. Underwater investigations of juvenile tanner crabs in the Bering Sea have shown that they are swept up by the flow of water over trawl footropes and left undamaged inside the trawl. A roller or weight traveling at 6 knots across the bottom may cause some damage to crabs unless they can sense the danger and escape before contact. This fact remains to be seen. In the case of the weight shown in Figure 25 escape over the top may be easier than escape over the roller. We might assume that roller or slab will not cause a significant reduction in the bio-film layer.

References

The Contact Drag of Towed Demersal Fishing Gear Components, F.G. O'Neill, et. al.

WDNR_POC_mech_mgt_final_03_01_2019.pdf

WDNR_Supplemental Mech_mgt_03_01_2019_final.pdf

MarshMaster_MM-2LX_Roller-Chopper-Specs_web.pdf

Channeling can occur when dry rolling as water pushed up from the ground by the pressure of the roller runs from high ground to low ground as shown below in Figure 26.

Figure 26 Channeling of sediment after dry rolling-photo D. Beugli Aug. 2019

Figure 27 illustrates additional roller configurations utilizing sectioned drums. At least one of these may contribute to the ejection of shrimp from their burrows by enhanced or cyclic pore pressure wave modifications. Some more detailed design and construction time might be necessary to produce and test these rollers. In that case these configurations might be attempted during the evolution of more simplified roller equipment after wet rolling is proven as a solution.

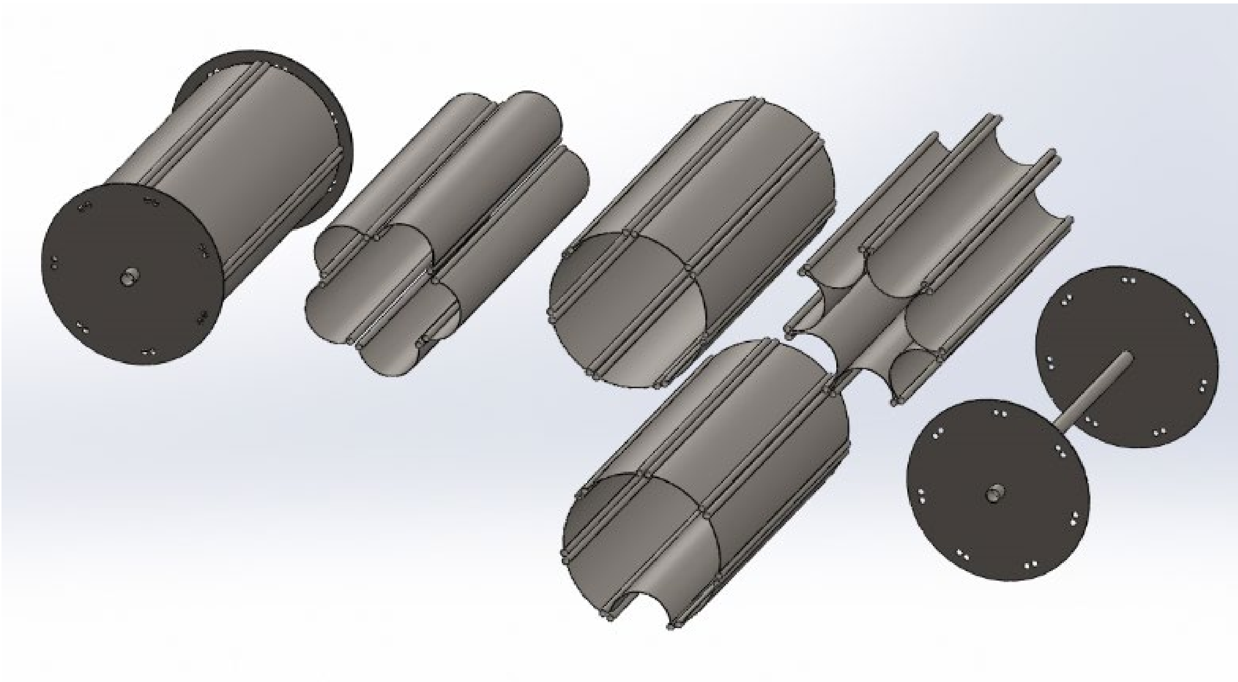


Figure 27 Possible roller configuration that might enhance the rollers ability to eject shrimp from their burrows.

5.4 Chain trawl and attachments

Chain trawling in the marine environment is an operation which drags a light or heavy chain through the water and over the seabed so the top few inches of sediment is turned and/or redistributed in the wake of the chain. This would be done using two vessels, large or small, towing a long chain between them. This could also be accomplished by anchoring one end of the chain and using a single vessel to tow the chain around the anchor. It is also possible that an anchor connected to a winch on the vessels could provide the motive force for chain trawling especially in shallow water where propeller clearance over the seabed is an issue. In the case of very shallow water the wash from a propeller can cause damage to the oyster bed and potentially move oysters off of a lease site.

After talking with oyster growers and looking at previous proof of concept (POC) trials chain trawling has the potential for the following benefits:

1. Turning up young ghost shrimp so settlement is disrupted and perhaps over the long run achieving a reasonable balance of oysters and ghost shrimp.
2. For oysters that are partially buried a light chain trawl would tumble the oysters up onto the seabed thus delaying burial in the sediments.
3. Increase the time for working an oyster bed as long as it is covered with water, especially if winches are used as the main propulsive force.
    a. The idea is to use floating platforms for chain trawling rather than land vehicles.
4. Larger sweeps are possible with a single long chain, in some cases as long as the width of a single oyster bed which may measure in 100 meter increments.
    a. Long chain assemblies can be used, for example tandem chains to double the effect in a single operation.
5. Chains can easily be handled on hydraulic reels, such as those used on offshore trawlers so deploying, hauling and storage is all mechanical and relatively simple.
    a. In some cases the chain can temporarily be left on the seabed for easy connection when the tide again gets high enough for a vessel.
6. Chains can be fitted with steel toggles or rubber disks to further turn up the soil.
    a. Ring link chains as shown in Figure 28 are commercially available and may have the benefit of turning up soil due to link shape.

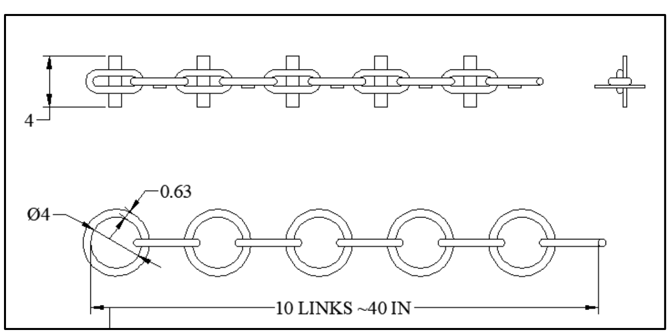


Figure 28 Toggle link chain and ring link chain

Chain trawling methods:

Pair trawling

Pair trawling consists of two vessels usually of equal size and power towing a single net or in this case chain between them. Naturally vessels with more power and deck equipment can handle longer chain and heavier chain. Skiffs on the other hand might be limited to chain type and lengths that can be lifted by hand or placed on the seafloor by a larger vessel and picked up from the skiffs by buoys located on the ends.

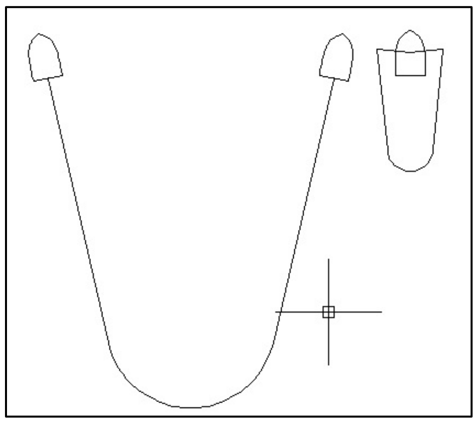


Figure 29 Chain trawling schematic showing pair trawlers and

Anchor Seining

Anchor seining, also similar to Danish or Scottish seining, is a technique where a buoyed anchor is set up and from it the boat lays out a ground line in a triangular fashion ending back at the start buoy. The anchored vessel then starts one or two winches and hauls the ground line (from one side or both sides) as it sweeps the area interior of the original triangle. For this operation each section of the chain moves at a different velocity relative to the bottom. Figure 30 shows a simplified version of this technique.

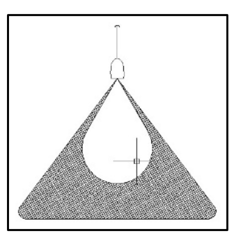


Figure 30 - Anchor seining schematic with cross hatched A. Area is completely swept when chain loop is completely hauled aboard.

Note: Pulling the chain from a winch(s) is more efficient than thrust generated by a propeller.

Power requirements

The operations described in the previous section were modeled using non-linear finite element analysis with the objective of determining the relative efficiency of each operation and a rough estimate of the forces required to move chain across the sediment typically found in Willapa Bay. The accuracy of the analyses is best used for relative understanding of the operations rather than the absolute values given for each simulation. This is mainly due to the lack of information about how chain reacts the sediment as it is pulled across the seabed, but also to limitations of the software used.

Chain friction across seabed

There have been very few measurements or even estimates of chain drag forces across seabeds. And as might be suspected there are very complex issues of weight, link size and shape, type of soil, geology of the sea bed, speed, tension and direction, etc. The best find of information so far is from a simulation program called OrcaFlex and its treatment of Coulomb friction cited in its instructions as follows;

OrcaFlex applies Coulomb friction between the line and the seabed. The friction force applied never exceeds μR, where μ is the friction coefficient and R the seabed reaction force.

Lines lying on the seabed often move axially more readily than they move laterally. This is represented by having different friction coefficients for motion in the normal (i.e. lateral) and axial directions. For intermediate directions, OrcaFlex interpolates between these two values.

Typical values

Published data are sparse. Some information is given in Puech (1984) and Taylor and Valent(1984), both of which distinguish between starting friction and sliding friction: starting friction is greater, to represent the "breakout" force. OrcaFlex does not, however, support this usually be conservative. The context of both of these references is the contribution of chains and cables to anchor holding power, so we assume the friction values given are axial. Transverse values will be greater, perhaps by 50% to 100%.

The values given below are recommendations from Taylor and Valent.

Sand (breakout/axial sliding/normal sliding)	0.98/0.74/1.48
Mud and Sand	0.92/0.69/1.38
Mud and Clay	0.90/0.56/1.12

Since OrcaFlex is not available for use in this study I have used a non-linear finite element program specifically developed for fishing nets, trawling and aquaculture called NEMOS (Numerical and Engineering Modeling of Ocean Systems) to make estimates of the forces required to pull chains across the seabed. Since some of the Willapa Bay seabed is near liquefaction, a worst-case scenario was assumed where some of the chain may be partially buried. In this case it seems reasonably conservative to set the normal sliding friction coefficient to 1.0 for axial sliding friction and 2.0 for normal sliding coefficient both of which are higher than values given in the above table. These values have been adjusted to suit the force application suitable to the NEMOS solver. Given these friction coefficient values and a haul rate of 2 kts (~1.0m/sec) estimated forces to pull the specified chain can be approximated.

There has been no estimate of setup time or turn-around time for each operation. The skiff pair trawl and single boat trawl are all assumed to travel in a straight line until each has covered 1 acre of seabed at the simulated width of the chain.

NEMOS models common parameters:

Water depth- 10 ft

Towing/Hauling speed- 2 kts

Pair trawling skiffs-1, light chain:

Chain type- 5/8” deck lashing chain, long link

Chain weight per foot (in air)- 2 lbs/ft

Chain Length- 180 ft.

Warp type/length- Dynema rope/66 ft

Distance between skiffs- 164 ft

Spread between chain ends- 109 ft

Towing force in Y-direction- 558 lbs

Towing force to keep skiffs apart-184 lbs

Total propeller thrust- 588 lbs each vessel at 2 kts

Time to sweep 1 acre at 2 kts- 1.98 min

Relative power (force times velocity)- 6.82

Pair trawling skiffs-2 heavy chain:

Chain type- 1-1/8 stud link chain

Chain weight per foot (in air)- 6 lbs/ft

Chain Length- 180 ft.

Warp type/length- Dynema rope/90 ft

Distance between skiffs- 164 ft

Spread between chain ends- 101ft

Towing force in Y-direction- 1600 lbs

Towing force to keep skiffs apart-562 lbs

Total propeller thrust- 1695 lbs each vessel

Time to sweep 1 acre at 2 kts- 2.14 min

Relative power (force times velocity)- 20.71

Single boat trawling from booms

Chain type- 1-1/8 stud link chain

Chain weight per foot (in air)- 6 lbs/ft

Chain Length- 90 ft.

Warp type/length- Dynema rope/90 ft

Distance between booms- 60 ft

Spread between chain ends- 34ft

Towing force in Y-direction- 494 lbs

Axial force on each boom- 85 lbs

Total propeller thrust- 980 lbs

Time to sweep 1 acre at 2 kts- 6.36 min

Relative power (force times velocity)- 6.0

Anchor seining from stationary vessel hauling with two winches

Chain type- 5/8" deck lashing chain, long link

Chain weight per foot (in air)- 2 lbs/ft

Total chain Length- 1207 ft.

Base of chain triangle- 500 ft

Each leg of triangle- 353 ft

Total area of initial triangle- 0.71 acre

Towing force in Y-direction- Not simulated

Towing force to keep skiffs apart- Not simulated

Total propeller thrust- Not simulated

Time to sweep 1 acre at 2 kts- 4.17 min

Relative power (force times velocity)- Not known

Other configurations

The previous simulations represent the most likely scenarios to be tried as a first attempt at chain trawling, with the single boat chain trawling expected to be the easiest to implement. If chain trawling has utility for the oyster farmers other more sophisticated setup and rigging is possible. A few possibilities are as follows:

- different chain sizes and weights
- link configurations
  - toggled links
  - ring links
- three tow warps for single boat chain trawling to increase spread
- trawling around a single fixed anchor with a longer chain
- trawling to two fixed anchors similar to pair trawling
- trawling with otter boards to increase spread from a single vessel

Recommendations

If it is judged worthwhile by the oyster growers the simplest test of the technique would be to use a single boat oyster scow towing a length of chain from its booms as long as the vessels structure was suit to the expected loads. Even though this test would have the least amount of spread between chain ends for any of the examples cited above it would be on the order of 4 times the sweep coverage of any previous POC tests, with the possibility of fasters towing speeds. Before any such test was to be attempted the following issues should be resolved:

1. Heavy delta plates fitted with swivels need to be attached to each end of the chain to prevent the towing warp from twisting should the chain rotate under tow.
   a. The swivel is an absolute necessity of toggle chain is used as it is designed to rotate.
2. The chain should be rigged with underwater cameras to observe the action relative to the bottom.
   a. Chain rotation could be problematic depending upon how the cameras were rigged
3. Rigging on the vessel may have to be modified to ensure the chain can be easily deployed and retrieved.

5.5 Eductors

Technical description of an eductor

An eductor is a machine which generates suction by the Bernoulli principle which identifies a moving stream of high velocity water or air as having a lower pressure than the surrounding volume of stationary or slower moving fluid. This property is most familiar in the lift generated by an airplane wing caused by the air moving faster over the upper surface of the wing compared to the air moving across the lower surface. Important for this study however is the fact that an eductor can be used to move fluid, air and solids by the same principal. Figure 33 shows a schematic of the operating principal.

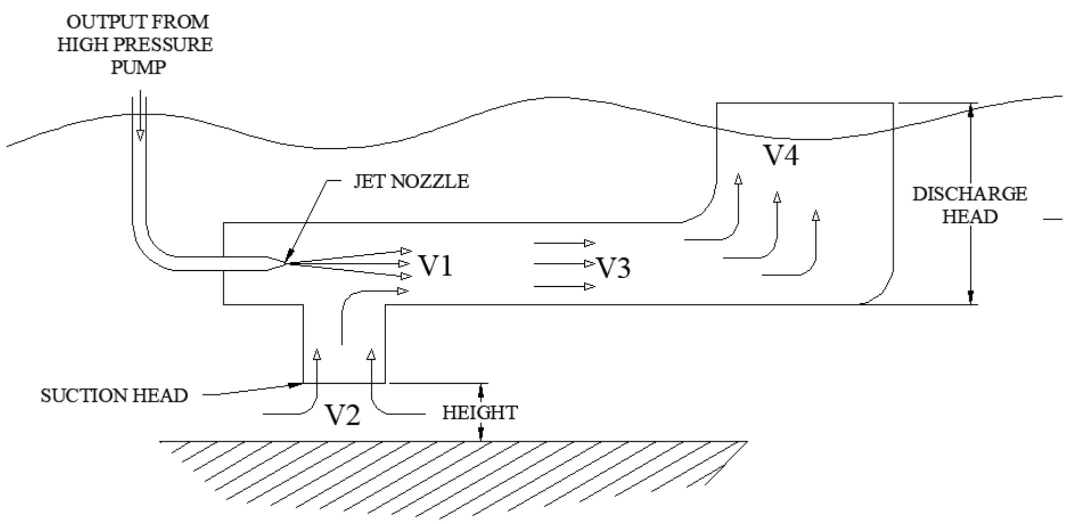


Figure 31 The eductor schematic

The motive force for the eductor is the output from a high-pressure pump which can be located on a vessel above the eductor or located submerged as part of an eductor sled.

1. The motive pump causes a high-pressure stream of water at velocity **V1**.
    a. High pressure pumps are used on the oyster scows to wash gravel or shells off the deck and onto the beds.
2. The high velocity produces a low pressure in the suction head which in turn produces an inflow velocity, **V2** which can entrain a slurry of water, sediment and solids.
    a. The ability to vacuum up solids depends on the height above the sediment.
3. The velocity **V3** is the combination of the velocities **V1+V2** which is the velocity of the slurry
4. The discharge pressure can be increased as the velocity **V4** is slowed down in a larger diameter outlet.

   a. This higher pressure gives the eductor the ability to lift the slurry above the motive force water stream.
      i. This is a change of kinetic energy of motion to potential energy of gravity
   b. It may not be necessary to increase outlet pressure if stream velocity **V3** is the ultimate design goal as in the case of forcing shrimp through a kill screen.

Lost Ground Recovery

While using an eductor device as an independent activity may not have utility to the everyday operations of the oyster farmer, it has some real possibilities for other stakeholder strategies to recover ground lost to ghost shrimp. If an eductor sled turns out to be effective, its periodic or even annual use over the same lost grounds may give eel grass prairies a chance to reform, thus improving the ecological recovery of the bay. When recovery of lost ground is a goal an inter-agency and comprehensive stake holder strategy such as that used to control spartina grass could be employed.

Contact with an eductor company (Elmridgejetapparatus.com) gives some idea of the performance specification for a typical eductor:

1. Slurry specific gravity=1.75
2. Motive pressure 100 psi, motive flow-850 gal/min.
   a. The high stream jet V1~17.6 ft/sec
3. Suction pressure -2.17 psi less than hydro-static ambient pressure outside the eductor.
   a. 5 ft/sec pickup velocity in a 1 sq ft such hood.
   b. Suction capacity for sediment will depend on the proximity of the suction hood to the sediment.
   c. A suction pressure of 2.17 psi acting on an oyster with a shell of 5" x 3" would exert an upward pressure of 32.55 lbs.
4. Suction capacity-2250 gal/min
5. Discharge flow-3100 gal/min
   a. Ideal efficiency of this eductor--discharge flow/motive flow~3.65/1
6. Maximum discharge pressure-3.8 psi
7. Theoretical Horsepower for motive pump~50 hp
   a. Actual shaft horsepower~82 hp.

Another company's online specifications for a submersible ROV eductor pump are listed as follows: ZJS-100 ROV Dredge Pump

1. Motive pressure 2570 psi to 4000 psi, motive flow rate~ 24 to 38 gal/min
2. Suction hose diameter-4" and discharge hose diameter-6"
   a. Suction area~0.09 sq ft

   b. Discharge area~0.20 sq ft.
3. Water suction up to 1103 gal/min, solid removal up to 0.50 tons/min
   a. Water velocity into suction hose~27 ft/sec
   b. Based on water discharge ideal efficiency~ 29/1
4. Jet nozzle- 0.38" dia up to 0.79" dia.
5. Total unit weight: 103 lbs in air and 42 lbs in water.
6. Requires ~ 82 shaft horsepower

These specifications serve as an example only on the extreme ends of motive input and represent only one of nearly endless configurations and specs which might be used to advantage in Willapa Bay for:

a. Moving oysters from one bed to another
b. Harvesting oysters
c. Harvesting clams
d. Reclaiming lost ground by killing any shrimp within the eductors influence.

If an eductor is used on a sled type device, besides adjusting motive force, the speed over ground becomes important to how deep the suction will dig into the sediment. It can be assumed that as the eductor sled is towed faster over the sediment it will only affect the objects and sediment closer to the top of the sediment. It is possible to lift the slurry to the deck of a vessel where the slurry is separated according to components. In all versions of the eductor envisioned for Willapa Bay sediment would be dispersed again over the seabed rather than carted off to a disposal location.

A model of successfully test eductor sled used for deep water manganese model mining is given in Figure 32. In this case a single submersible pump supplied the motive power to 4 eductor hoods.

Figure 32 - Model of a deep water (13000 ft) eductor sled tested for manganese nodule recovery

Several small gold mining eductor dredges are readily available and may serve as convenient frameworks for test beds that can be modified and adapted for POC testing as are several ROV eductor dredges.

http://www.akmining.biz/mine/keene_8_inch_suction_gold_dredge.htm

https://irp-cdn.multiscreensite.com/6d28e3e1/files/uploaded/EASYDREDGE%20ops%20manual%20May%202019.pdf

http://www.advancedmarineinnovation.com/DataSheets/DataSheetZJS100b.PDF

5.6 Electro-Pulse Trawling

Figure 33 shows a schematic of a possible electro-pulse trawl array. Note that in this version a chain is used to turn up the bottom in front of the pulsed array. It may not be necessary to use a chain at all. If the lost ground includes sparse eel grass islands that could serve as incubation sites for eel grass prairies being established on lost ground, the chain will disturb these grass islands. The spacing of the array and the electrical field should be investigated to determine the optimum levels electrical impulse. The normal towing speed for this gear is on the order of 6 kts (10.08 ft/sec). At this speed this trawl gear will cover and area of 202 sq ft/second and will cover 1 acre of lost ground in approximately 3.5 minutes. It is possible to purchase the equipment already set up from an EU supplier as the Dutch have resisted the EU rules against pulse trawling and are still using the technique as of this writing.

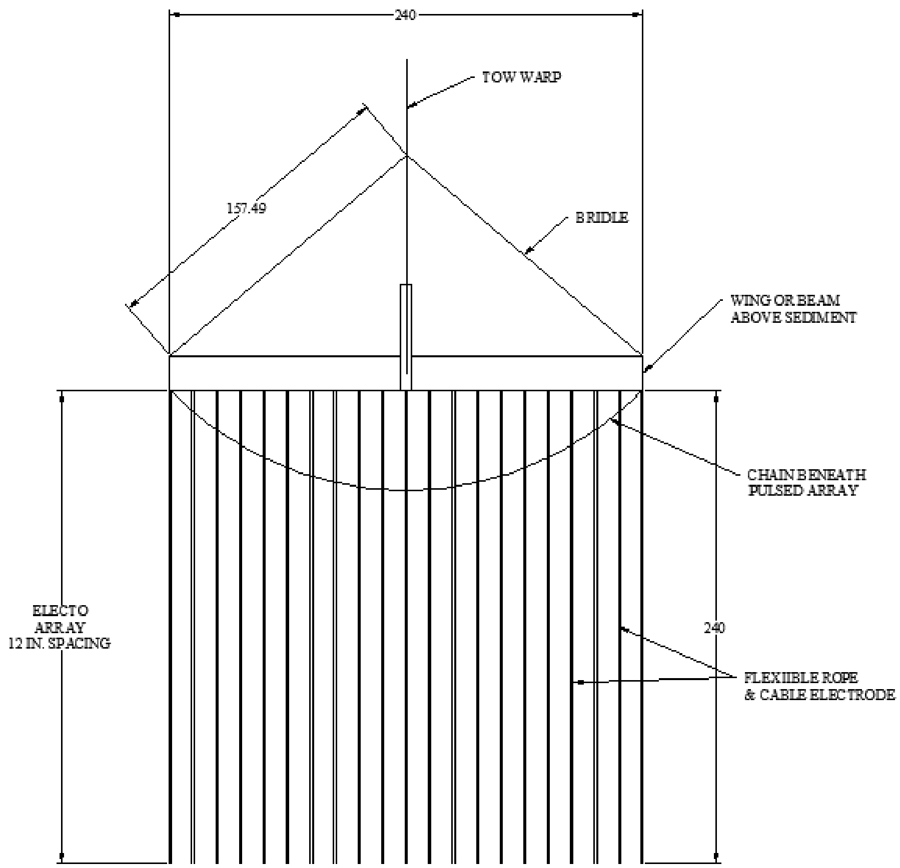


Figure 33 An electro-pulse trawl schematic

References

3) Determining the safety range of electrical pulses for two benthic invertebrates brown shrimp (Crangon crangon L.) and ragworm (Alitta virens S), Maarten Soetaert, et.al.
4) The Potential Use of Electricity to Control Burrowing Shrimp in Oyster Aquaculture Beds. B. Dumbauld and L. Harlan

5.7 Bed Matts

Shrimp Control on "Lost" Ground Utilizing Biodegradable Open Weave Mat Barrier Treatment

Objectives

The objective of this concept is to reclaim "lost ground", ground that cannot be used for either ground or above ground oyster culture, by the evacuation of ghost shrimp and active densification of the sediment. This would be done by the placement of a biodegradable open weave mat on the surface of the bed, topped with or without sediment, and seeded by eelgrass rhizome-roots, such that:

- the ground could be used for either type of oyster culture as soon as possible. (with ground culture by hand or light touch mechanical methods),
- other organisms are minimally affected while barrier is in place,
- that ghost shrimp populations will be controlled to a level that allows on and above ground oyster culture, and
- when the mat decomposes all effects are sustainable (assuming light touch farming continues)

The expectation of success in achieving these objectives is high**.**

Constraints

The main obstacle is the cost for application of mats on large commercial acreages. Possible mitigation of such is reduced pricing of mats for bulk orders from country of origin. The origin of most if not all such biodegradable mats is India. Bulk orders can be ordered directly from Indian manufacturers FOB Seattle, bypassing at least one middleman. At time of writing bulk prices are unknown but can be up to 50% less than the cost of the amount needed for field testing (acquired from local dealership).

A secondary obstacle is that ghost shrimp evacuated to the edges of mat may tend to persist in that location. A possible mitigation of such might be control of the ghost shrimp at mat edges by mechanical means, e.g. recommended concepts of roller and/or eductor. Mats also can be placed in a checkerboard pattern with enough space in between the mats to allow for shrimp control.

Field testing

The field testing of the concept can be accomplished in one season with materials that are readily available. The field testing of the eelgrass seeding of the mats can be partially accomplished in conjunction with mat testing and/or informed by the testing recommended elsewhere in this report. The cost of commercial sized treatments will not be trivial but the ground may be able to be used for oyster culture within months after mats and rhizome-roots are placed, and be sustainable for such use into the future.

Field Testing of eelgrass transplantation

Rigorous experimental testing in two California estuaries offers strong evidence that the rhizomes-roots of Z. Marina eelgrass is effective in displacing ghost shrimp, and furthermore that rhizome–root structural mimics made of nylon and adhesive sealant and placed 2+cm into the sediment at the same density as eelgrass transplants, are equal or greater in effectively displacing ghost shrimp as is live eelgrass (Castorani et al. 2014).

Both the live eelgrass and the rhizome-root structural mimics transplants had rapid negative impacts on ghost shrimp, reducing shrimp populations from 40 burrows / m2 to 0+/ m2 in 7 weeks and 80 Burrows/ m2 to 20/m2 in 8 weeks.

The field tests show that control of shrimp populations can be accomplished by transplantation of eelgrass, that biodegradable open weave mats in many ways mimic rhizome-roots structural mimics and as such may perform similar functions, and that the mats and the transplantation of eelgrass have a high potential to be a synergistic combination.

It is posited that the eelgrass rhizome–root matrix, or concomitant changes to sediment structure, interferes with the ability of ghost shrimp to form or maintain burrow surface openings or other burrow structures (e.g., turnaround chambers), or otherwise interfere with their behavior. We infer that the “other behavior” might be that in dense enough eelgrass the attendant rhizome-root structure would tend to lessen the amount of burrow openings that would be possible and that it also would increase the urge of shrimp to evacuate the area.

The structure of an open weave mat can be said to mimic the rhizome–root structural mimic, and as such would inhibit the ability of shrimp to access the ground surface, adding to a ghost shrimp’s lateral evacuation from the site.

The effects that eelgrass and eelgrass structural mimics have on burrowing shrimp certainly may be some of the same effects enabled by the application of biodegradable open weave mats have had in field testing.

We hypothesize that the structure of an open weave mat roughly simulates the effect of a rhizome–root structural mimic, and that it can also inhibit the ability of shrimp to access the ground surface or construct a proper burrow mound, adding to a ghost shrimp’s urge to laterally evacuate from the site.

Furthermore, seeding a biodegradable mat with live Z. Marina rhizome-roots prior to placement, or transplanting such before or after mat placement, would quicken both the removal of shrimp and the enhancement of ground stabilization. After the mat decomposes the eelgrass will remain to help stabilize the ground and discourage the shrimp from repopulating. If oyster harvesting is accomplished by hand, or other lighter touch methods such as those recommended in bed conditioning devices, it also will enhance the sustainability of oyster farming.

We are not recommending the use of non- biodegradable mats nor the frosting mats with gravel. We are however recommending testing the relative efficacy of mats and eelgrass transplantation with and without a 2+ inch topping of sediment.

Field testing of biodegradable bed mats

We are looking at the use of open weave biodegradable mats to be laid directly on top of lost ground. It is recommended that field testing be done for a minimum duration of 6 months, spanning the spring and summer months.

Four types of open weave biodegradable mats are recommended to be tested, all in the life expectancy range of 4 to 6 years, and all with Coir (coconut fiber) fabric as the only or main component.

Each type of mat should be tested in two ways: a mat alone and a mat with a 2+ in topping of sediment, 8 mats total

There are many standard methods that are available for securing the mats. However, given the nature of the site it is suggested that at a minimum two types of securement be tested:

- Topping the mat with a sediment layer of 2+ inches. This should be tested both by itself and with another complimentary system such as staking or the placement of weights.

- Securement with # 3 steel rebar stakes. The spacing, length and shape of rebar may be informed by the current POC by the Burrowing Shrimp Field Test Pilot Project. If not, it is recommended at minimum to test of both 1‘-6” and 3’-0” #3 steel rebar with a J hook at a 10 ft minimum spacing. The stakes (which are reusable) should remain until the mat is properly bedded by normal sediment flow.

It is intended that each mat would be seeded with eelgrass rhizomes –roots and/or transplanting of such done before or after the placement of the mats. The manner in which seeding is to be done is dependent on coordination with, and informed by, the timing of the actionable recommendations for eelgrass transplantation recommendations in Looking Forward – Eelgrass Restoration section of this Report. In lieu of this: for mats that are seeded, rhizome-roots should be attached at the mat bottom; transplanted rhizome-roots should be placed at a depth of 3+- cm.

The recommended duration and span of testing is recommended to be 6 months minimum, spanning the spring and summer months.

Each mat should be overlapped to cover an area of 50 X 50 ft. minimum. If desired, the mats may be placed in a checkerboard fashion with enough space in between the mats to allow the testing/use of mechanical means, e.g. recommended concepts roller and/or eductor, to control ghost shrimp that will be evicted to the edges of the mats.

The following are the types of mats identified at time of writing to have the best probability of success are:

1. 900 Coir (open weave with 1/4-1/2" approx. openings)
2. 1000 Coir (open weave with 1/8-1/4" approx. openings)
3. Nedia KoirWrap™700 or equal (double layered -with outer layer of open weave coir fabric and an inner layer of jute fabric)
4. Nedia KoirWrap™900 or equal (double layered -with outer layer of open weave coir fabric and an inner layer of jute fabric)

Figure 34 Coir 900, 1000 similar

There are other options or additions to further consider such a composite similar to a KoirWrap but with 1000 Coir open weave fabric encapsulating a loose matrix /matting of unwoven coir fiber similar to the mat shown below

Figure 35 Coir Mesh: to be used as a middle layer of a composite mat

Also, mats can be engineered, and purpose built - e.g. the braided fabric can be manufactured with more, lighter or heavier strands, the weave can be made smaller or larger, and composite mats can be made of any combinations of materials. It is recommended to use only Coir fabric for single layer mats and for the outer portions of composite mats.

Field testing cost estimate for 2500 square foot proof-of-concept test and evaluation

Costs are order of magnitude with a contingency of 50%, Duration of field testing is assumed to be 6 months. The costing is given for materials, installation of materials, monitoring, data collection, reports and recommendation. At time of writing the seeding and/or transplanting of eelgrass has not been costed.

Materials	$7,000
Installation	$13,000
Monitoring/ Data Collection	$17,000
Reports/ Recommendations	$30,000

Commercial application

Deployment

The installation of the mat system entails laying the mat(s), securing the mat(s) and transplanting the rhizomes roots.

The mat can be placed continuously as one large mat, or as smaller area mats laid in a checkerboard fashion with enough space between mats to allow shrimp control by mechanical means as informed by other bed conditioning tools of this report, e.g. rollers or eductors. In either case the placement of the mats should have overlap between individual sections of 1+-ft. The mats are available in rolls 6 to 16 ft. wide by 50 to 200 ft in length. However, it is possible to custom order mats of different lengths and widths, especially if ordered in bulk directly from the manufacturer.

It is thought that the most efficient and effective way to install the mats is to set the mat rolls in their approximate position on the bed from a dredge boat, skiff , or scow near the low stage of an outgoing tide, dependent on roll sizes and the amount to be placed during one tidal period. The mat rolls may come wrapped on a rigid center pole but if not, one should be installed prior to dropping it onto the bed. Dependent on the tidal flow and water depth at placement, it may be prudent to weight the roll appropriately. At low tide the mats can be positioned and unrolled manually. Purpose built spools – rods and spool end caps to be attached prior to rolling, can be built to facilitate placement. Placement in position and then securement of the mats should be done as soon as possible but no later than the turning of the tide.

There are many standard methods that can be used but at time of writing it is recommended that that it be done by one of two methods, or as informed by field testing. One method is the use of #3 steel rebar whose size, shape and spacing will be informed by field testing, and the other is by the frosting of a 2+ in. lift of sediment atop the mat.

If securement by staking is chosen, the stakes should remain in place until the mat is properly bedded by normal sediment flow.

If securement is by placing of sediment atop the mat, dependent on the timing, additional securement by staking or placing of weights on the mat (rock, sandbags, oyster clutch etc) may need to be done before frosting is done. Sediment can be sourced from the lost ground. This can possibly be accomplished by use of an eductor which might be available at the time of application from recommendations in the Bed Conditioning Tools section, or that is commercially available for such use.

Seeding by rhizome-root seeding of the mats or transplantation before or after mat placement should be as informed by field testing and/or recommendations in the Looking Forward section of this Report.

Figure 36 Large (Land Based) Coir Mat Application

Commercial Application Cost Estimate

Costs are order of magnitude per 1 acre for installations of >= 5 acres, with a contingency of 50%. Mats are assumed bulk ordered from country of origin FOB Seattle. The costing is given for materials and their installation. At time of writing the seeding and/or transplanting of eelgrass has not been costed.

Mat with sediment topping:

Materials	$4,500
Labor	$2,000

Mat without sediment topping:

Materials	$4,500
Labor	$2,500

6. Looking Forward – Climate Change and Ecosystem Details

Climate, farming, and ecosystem action

Including suggested research and action agendas for each topic

Contents

6.1 Introduction to Looking Forward

Willapa Bay and Grays Harbor, like many estuaries throughout the United States and the world, have been impacted by human activities that have had detrimental effects on the health of their ecosystems. The anthropogenically induced changes in the ecosystems of Willapa Bay and Grays Harbor were brought on by activities both in and from outside the estuaries. Activities from the outside include the burning of fossil fuels and the release of greenhouse gases, deforestation (collectively contributing to climate change), logging in the watershed, and commercial fishing. Those from within the estuaries include the introduction of non-native species and the large-scale conversion of intertidal lands into agricultural areas and the attendant activities of dredging, harrowing and application of chemicals.

These have had and will continue to have negative effects on most estuarine habitats and organisms – including commercially important fish and shellfish. Predator-prey relationships are disrupted, migration patterns are altered, food sources may be diminished, and protective cover may be lost.

Coastal estuaries are critical ecosystems for a variety of wildlife species, serving as important roosting and forage habitat for migratory birds and nursery habitat for out-migrating juvenile salmon (Groot and Margolis, 1991).

Willapa Bay has lost an estimated 64 percent of its estuarine wetland primarily through diking, channelization, dredging and filling (Woo et al., 2018). Several studies have addressed the need for restoration of these critical estuarine habitats to benefit a variety of dependent species. These important restorative activities will become increasingly important in providing a food source for cultured shellfish in the Willapa and Grays Harbor estuaries.

The framework within which aquaculture is governed and managed throughout the world is changing to become more environmentally and socially acceptable just as wild-capture fisheries management has evolved to become more responsible, environmentally sound, and to consider the role of species within an ecosystem rather than focusing just on individual species. Similarly, there is a movement to adopt an ecosystem approach to aquaculture (EAA) in many countries including the United States, at least at the Federal level at this time. But most importantly, the consumer is demanding that we provide healthy, safely, and sustainably farmed products.

Objectives

Our objective is to encourage the rehabilitation and the long- term ecological sustainability of the Willapa Bay and Grays Harbor watersheds, and to mitigate the projected impacts of climate change effects. We support efforts to conserve and restore biodiversity and to ensure and maintain continued economic viability of commercial shellfish farming. Recommended actions for rehabilitation should reduce human impact on the natural environment and prevent or lessen further environmental degradation. Recommended actions for the mitigation of climate change effects will provide alternatives for the continuation of the commercial shellfish industry should projections of ocean acidity and warming prove true. They will also identify some long-term options for consideration.

While the apparent irruption of burrowing shrimp has disrupted the shellfish industry and has led to the loss of intertidal areas for oyster culture, they are a native species and do play a prominent role in the ecology of the estuaries. They are part of the food chain, aerate the sediment, provide for biological diversity and habitat within their burrows for multiple organisms including the blind goby, three species of pea crabs, two species of clams, copepods, shrimp, polynoid worms, and isopods; as such, they should not be completely eliminated.

Absent historic and current anthropomorphic activities these estuaries presumably functioned sustainably.

6.2 Eelgrass Restoration

Introduction to Eelgrass restoration

Eelgrass restoration is becoming increasingly important as global eel grass populations are diminishing. The Nature Conservancy has identified 19 threats to eelgrass of which the following apply to the west coast: increased sedimentation, coastal development, sea-level rise, sea temperature changes, anthropogenic contaminants, and aquaculture (Sherman, K. et al.2018).

Eelgrass provides ecosystem services and can serve as a biological indicator of ecosystem health: its presence helps mitigate the impact of excessive nutrient input to the estuary from human activities (Sherman, K. et al.2018). The meadows have been identified as providing "regulating services" by lessening the impacts of climate change including mitigating for ocean acidification, a problem for the shellfish industry, in particular, as it interferes with their growth and many susceptible planktonic organisms at the base of the food chain. It can also affect the behavior of some fish species by dulling their chemo-sensory abilities. Eelgrass has been estimated to sequester carbon at a higher rate per unit area than terrestrial forests, and store a disproportionate amount of carbon for their relatively small area (Postlethwaite, 2018).

A reduction in eelgrass acreage has a concomitant reduction in the sub-surface area with rooting and rhizome structure that normally provides sediment stabilization as well as barriers to burrowing shrimp. In the absence of, or reduction in rhizome structures, shrimp can more easily burrow or tunnel through the sediment, eventually rendering it soft, unstable, and ultimately unusable.

Eelgrass meadows are major contributors to marine primary productivity and contribute to the food web in support of healthy estuarine and coastal ecosystems. Many studies have documented a significant diversity of plant and animal life associated with these eelgrass meadows, including epiphytes, epibenthic organisms, infauna, and nekton. Healthy beds form dense underwater meadows that provide substrate for diatom and algae growth which are fed upon by other visitors or inhabitants of the estuary. The eelgrass provides habitat and protective cover for a myriad of marine species. These meadows are recognized as nursery areas for many marine and anadromous species and, as such, have been designated as Essential Fish Habitat for juvenile salmonids.

Historical records suggest that Willapa Bay had over 7,000 acres of eel grass in the 1880s which grew to close to 12,000 acres by 1954; however, by 1990, the eel grass area had decreased to 1,260 acres (Sherman, 2018), close to a 90 percent reduction in eelgrass. This would have had a significant impact on the bay, eliminating much protective structure for juvenile fish and crustacean species, interfering with the functioning of the food web, reducing biodiversity, and generally rendering the bay less hospitable for predators of burrowing shrimp.

Restoration Techniques

Eelgrass restoration programs exist in most, if not all, coastal states and nations. Many eelgrass planting and seeding methods have been tested in diverse environments and under different conditions. Some methods rely on "seeding" and others on transplanting existing eelgrass with their rhizomes. Unfortunately, success is not guaranteed and what works in one environment may not in another.

Examples of different restoration methods are listed in Appendix A with success rates identified where available. The list is by no means exhaustive but demonstrates the similarities and differences in approaches. Methods will need to be tested for different sediment bottoms, wave action, competing plants, etc. The technical report *Eelgrass (Zostera marina L.) Restoration in the Pacific Northwest: Recommendations to improve project success (2008)* should be consulted prior to engaging in one of these or other restoration project.

Restoration Recommendations

Castorani et al. (2014), in *Disturbance facilitates the co-existence of antagonistic ecosystem engineers in California estuaries*, posited that planting eelgrass (*Z. marina*) in an area with burrowing shrimp (*N. californiensis*) would cause the shrimp to vacate the area and not return as long as the eelgrass remained in place. Several experiments were conducted:

- *Z. marina* plants with rhizomes were planted with bamboo staples, to keep them in place, into test plots with burrowing shrimp. The plots were monitored for seven months.
- In a second experiment burrowing shrimp were placed into eelgrass plots and allowed to burrow in to see if they could outcompete the pre-existing eelgrass. These were monitored for one month.
- Structural root-rhizome mimics were built using polyurethane and nylon fibers and placed in plots with ghost shrimp to see if the shrimp would react the same way as when faced with real eelgrass.
- Two perturbation experiments were conducted; one causing perturbation on the edge of a plot to see if shrimp would colonize laterally. The second perturbation was created in the center of a plot to see if there would be postlarval colonization.

The experiments demonstrated that local ghost shrimp densities declined rapidly following the addition of eelgrass in experimental plots. When transplanted into eelgrass patches the ghost shrimp failed to persist. The structural root-rhizome mimics were successful at keeping the burrowing shrimp out too. The only result that was disappointing was that ghost shrimp were more successful at trying to colonize through an edge-perturbation. The authors posited that the rhizome-root structures did not allow shrimp to construct their traditional burrows.

We are proposing that this promising experimental result for limiting burrowing shrimp be repeated in several areas of Willapa Bay to determine whether similar results can be obtained.

Public – Private Restoration Partnerships

NOAA established a Community-Based Restoration Program in 1996 which continues to exist today; they provide technical and financial assistance for restoration projects that ensure fish have access to high-quality habitat. Awards are granted to all sectors including non-profit organizations; federal, state, and local government agencies; tribes; private sector businesses; and academia. The program encourages community participation to help educate the community about conservation and stewardship, engender community pride, and promotes community support and volunteer participation.

In British Columbia, from 2002-2004, 1000 volunteers mapped 12,000 hectares of eelgrass habitat. Over time the volunteer community has continued its involvement by restoring damaged or destroyed eelgrass. The next step is involvement in shoreline work and other restoration projects. There are coordinators to manage the mapping, monitoring, and restoration activities of the volunteer eelgrass network. The volunteers are proactively encouraging stewardship and working with, rather than in opposition, to managers and NGOs.

Eelgrass restoration: Suggested research and action agenda

1. Repeat the transplantation process outlined by Castorani, planting eelgrass in several locations in burrowing shrimp areas
2. Design transplanting project to be conducted in oyster reserve
3. Test planting methods using seed and rhizomes in different areas
4. Review existing volunteer programs for eel-grass mapping and/or restoration opportunities.
5. Encourage public-private participation (planting by NGOs, community, industry, and state).
6. Seek funding for public-private eelgrass restoration through the NOAA Community-Based Restoration Program.

6.3 Natural Predator Restoration

Introduction

It has been hypothesized that burrowing shrimp (*Neotrypaea californiensis*) populations in Willapa Bay and Grays Harbor have been increasing as a result of habitat and ecosystem changes caused by shellfish grower activity, such as dredging, as well as due to climate change – which is being accelerated by human activities including damming, logging, allowing agricultural run-off, overfishing and bycatch.

Many predators of burrowing shrimp have been identified including a variety of fish species, crab, and birds. These include the Pacific staghorn sculpin (*Leptocottus armatus*), green sturgeon (*Acipenser medirostris*), white sturgeon (*Acipenser transmontanus*), Pacific herring (*Clupea pallasii*), Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisuch*), chum salmon (*O. keta*), cutthroat trout (Salmo clarkii), flatfishes, and Dungeness crab (*Cancer magister*). Some of the birds identified are the Long-billed curlew, Western gulls, and the Willet. Gray whales (*Eschrichtius robustus*) have also been known to consume large numbers of burrowing shrimp in estuaries and Puget Sound during their migration between Mexico and the Arctic. More detail on each of these species including their feeding habits in relation to burrowing shrimp can be found in Appendix B.

Other fish species have been identified as predators of burrowing shrimp in Washington estuaries as well as estuaries in California and Oregon. It is assumed that one of the reasons for decreased predation may be due to changes in habitat conditions including inadequate protective cover, rising water temperature, ocean acidification, and inadequate food resources.

Fluctuations in plant and animal species diversity and populations have disrupted predator-prey relationships resulting in further exacerbation of population changes. For instance, the loss of eel-grass habitat may have contributed to the reduction in the numbers of juvenile fish species that may feed on burrowing shrimp while in the bay.

Conservation Hatcheries

Conservation hatcheries exist in the state of Washington for salmonids, white sturgeon, pinto abalone, and Olympia oysters. These intervention programs are designed to preserve and enhance depleted populations of fish and invertebrates by increasing population size through protection and propagation in land-based hatcheries. We are proposing that a conservation hatchery be constructed for the specific purpose of culturing two of the above listed species of bottom predators: the green sturgeon, and white sturgeon, for the Willapa Bay and Grays Harbor area. The hatchery would maintain captive broodstocks of these species of fish. Juveniles would be grown at the hatchery site to a pre-determined release size, acclimated to their natural food source, and releases would be made into Grays Harbor and/or Willapa Bay.

We recognize that there is already a conservation hatchery program for white sturgeon in the middle Columbia, however we believe that there is need for additional white sturgeon releases in the coastal estuaries.

We suggest these two benthic predatory species as initial candidates based on their life-history patterns and preferred food organisms. These species share all or some of the following biological traits that may lend them well to captive rearing:

- known to be a predator of burrowing shrimp
- successfully cultured and bred in captivity
- resident in Willapa and Grays Harbor coastal embayments
- likely to home to release site

Predator restoration: Suggested research and action agenda

1. Convene a workshop on green sturgeon, modeled after the Columbia white sturgeon workshop held in 2017 in Coeur d'Alene by the NW Power and Conservation Council, including scientists and managers, Tribal representatives, and others as appropriate to examine the potential for a green sturgeon conservation hatchery for these watersheds and where it could be located.

   Among the sturgeon issues and questions to be considered in a workshop are:

   - Determine whether known genetic differences between Oregon and California stocks might be a limiting factor (northern and southern Distinct Population Segments);
   - Can you release a sDPS sturgeon stock from rivers other than those in California? the Columbia River? ;
   - Determine the likelihood that these large predators could be successfully cultivated at hatcheries located in Willapa Bay, Grays Harbor, or Columbia River estuaries;
   - Estimate cost of culture per released fish;
   - Identify any technology limitations, e.g., available water resources, etc;
   - Determine the likelihood that released sturgeon would successfully home back to the hatcheries or the release site;
   - Estimate risk to hatchery facilities associated with climate change;
   - Determine whether released hatchery sturgeon would prey on juvenile salmon species listed as threatened or endangered;
   - Identify likely hatchery sites;

2. Identify the full range of burrowing shrimp predators that currently and/or historically have resided in the estuaries for any significant period of time. Determine their population status.
3. Determine, to the extent possible, why their populations have decreased and whether or not their populations can or should be increased.
4. Increase eelgrass meadows to provide shelter for all predators and mitigate ocean acidification.
5. Tag white sturgeon to identify migratory movement between the Columbia River and the Bays.
6. Determine the likelihood that an increase in predator populations would increase predation on salmonids.
7. Determine whether hatchery salmonids will successfully prey on burrowing shrimp.

6.4 Climate Change

Introduction

The Intergovernmental Panel on Climate Change (IPCC), the United Nations body for assessing the science related to climate change, was created to provide policymakers with regular scientific assessments on climate change, its implications and potential future risks, as well as to put forward adaptation and mitigation options. A series of Fifth Assessment Reports (AR5)were issued in 2013 and 2014 including a shorter Synthesis Report (SYR), based on the other AR5 reports. The Synthesis Report states:

> *The Synthesis Report (SYR) confirms that human influence on the climate system is clear and growing, with impacts observed across all continents and oceans. Many of the observed changes since the 1950s are unprecedented over decades to millennia. The IPCC is now 95 percent certain that humans are the main cause of current global warming. In addition, the SYR finds that the more human activities disrupt the climate, the greater the risks of severe, pervasive and irreversible impacts for people and ecosystems, and long-lasting changes in all components of the climate system. The SYR highlights that we have the means to limit climate change and its risks, with many solutions that allow for continued economic and human development. However, stabilizing temperature increase to below 2°C relative to pre-industrial levels will require an urgent and fundamental departure from business as usual. Moreover, the longer we wait to take action, the more it will cost and the greater the technological, economic, social and institutional challenges we will face.*

Among the warnings they have presented are:

- The global ocean will continue to warm during the 21st century.

- Risks of harmful impacts on ecosystems and human systems increase with the rates and magnitudes of warming, ocean acidification, sea level rise and other dimensions of climate change.
- A large fraction of terrestrial, freshwater and marine species faces increased extinction risk due to climate change during and beyond the 21st century, especially as climate change interacts with other stressors.
- Global marine species redistribution and marine biodiversity reduction in sensitive regions, under climate change, will challenge the sustained provision of fisheries productivity and other ecosystem services.

The IPCC 5 (2014) report has been recommending that temperature increase be limited to 2°C or less however their 2018 Special Report, *Global Warming of 1.5°C*, discusses the significant differences between the impacts of global warming of 1.5°C and 2°C above pre-industrial levels, based on research and observations since the preparation of the 2014 report. This latest report states that the global temperature increase should be kept below 1.5°C to lessen "the negative impacts on intensity and frequency of extreme events, on resources, ecosystems, biodiversity, food security, cities, tourism, and carbon removal."

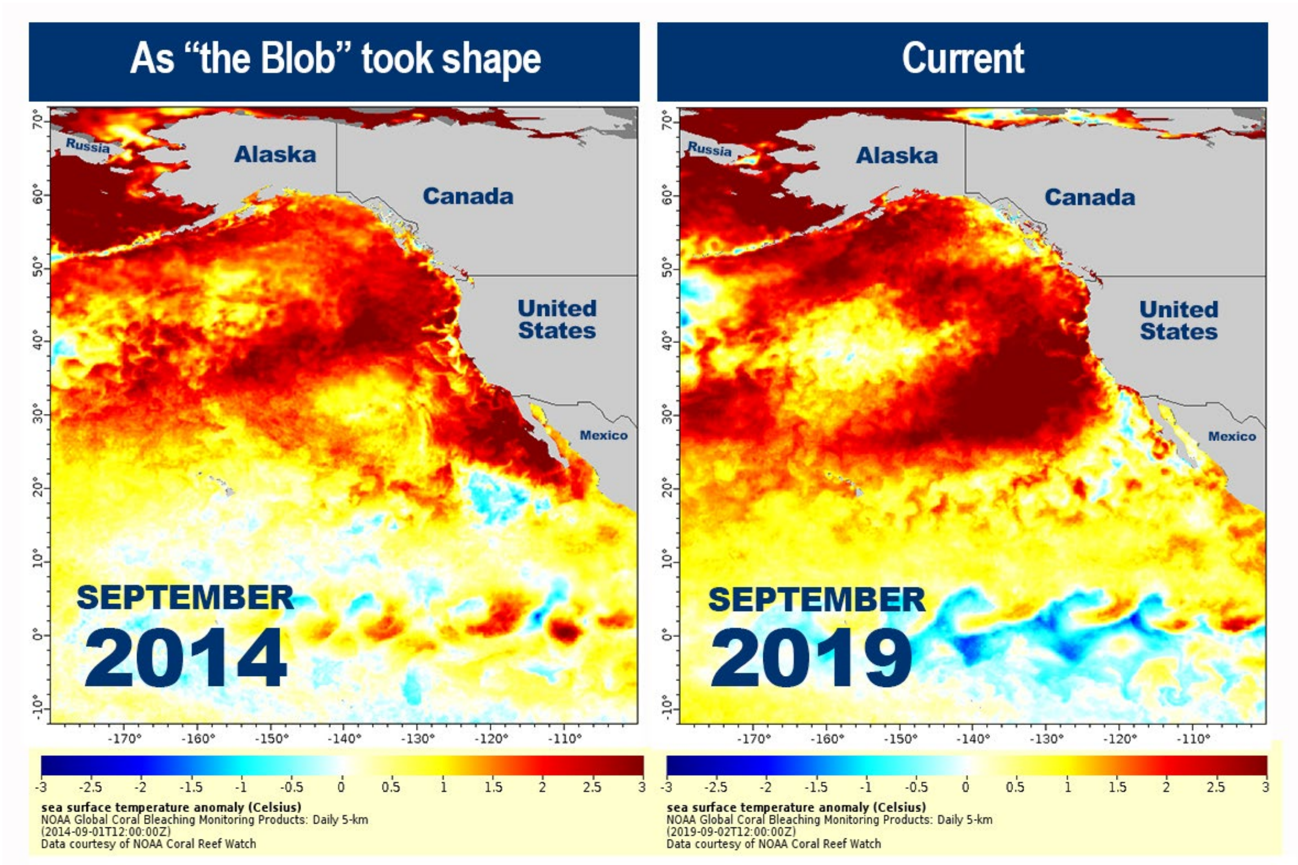
Later this year the IPCC will be releasing a *Special Report on the Ocean and Cryosphere in a Changing Climate* which is an assessment of the latest scientific knowledge about the physical science basis and impacts of climate change on ocean, coastal, polar and mountain ecosystems, and the human communities that depend on them. Vulnerabilities, adaptation capacities, and options for achieving climate-resilient development pathways will be presented.

Climate change has and continues to affect the Pacific Northwest; average temperatures are already 1.5°F warmer than the first half of the 20th century and winter minimum temperatures are 4.5°F warmer. By the end of this century temperatures could be between 5°F and 8.5°F higher than they are now, depending on actions taken to reduce green-house gas emissions (Vose et al. 2017). Documented climate change effects include more frequent and hotter heat waves, higher ocean temperatures, increased levels of CO_2 and ocean acidification, increased toxic phytoplankton blooms, changes in plankton composition and redistribution to new locations, and hypoxic areas creating dead zones, all leading to a decrease in food availability for many species.

In 2014 a marine heat wave in the eastern Pacific Ocean, stretching from Mexico to Alaska, demonstrated the serious impacts increased ocean temperatures can have. The "cause" of this marine heat wave, and those in other parts of the world, may have multiple causative agents including increased ocean temperatures due to climate change, and other weather/climate effects. NOAA has stated that, in this instance, "the warming is caused by a ridge of high pressure over the area that keeps winds calm and allows the sun to warm the water's surface" and that the absence of winds keeps from churning up cooler waters from depth to lower the temperature of the "upper waters".

The 2014 "patch" of warmer ocean water, named "the Blob", covered an area of 3 million square miles and was as much as 500 meters deep in places. It was responsible for huge losses of marine life, beginning with small planktonic organisms at the base of the food web, up to and including seabirds and marine mammals. Harmful algal blooms shut down the crab and clam fisheries along the west coast and toxic algae killed some fish or made them toxic to their predators – larger fish, seabirds, marine mammals, and humans. Lower feed quality and quantity became evident at all levels of the food chain resulting in weaker animals, and ultimately the loss of many predators. It has been reported that approximately 1 million young cod disappeared; five years later the fishery has yet to recover resulting in decreased allowable harvest levels for the industry. Salmon too were affected as warm waters decreased the amount of food available and moved food sources away from traditional feeding areas.

Today we are faced with what appears to be a repeat of this earlier marine heat wave anomaly – named the Northeast Pacific Marine Heat Wave 2019 (NEP 19). While not quite as large (yet) as the previous one at just 2.5 million square miles and only 50 meters deep so far, the Washington coastline is already experiencing some effects sooner than anticipated.



Sea surface temperature anomaly maps show temperatures above normal in orange and red. The new marine heatwave off the West Coast stands out in this map of sea surface temperature anomalies, with darker red denoting temperatures farther above average. The highest temperatures shown are more than 5 degrees Fahrenheit above average. Image from NOAA Coral Reef Watch, which corrects effectively for cloud cover.

Figure 37 Recurrence of the "Blob"

According to Nate Mantua, a research scientist at the NOAA Fisheries Southwest Fisheries Science Center, "It looks bad, but it could also go away pretty quickly if the unusually persistent weather patterns that caused it change." However, even if it were to "go away", sea temperatures are already higher than "normal" - by more than 5^{o} F in some places - and will have already begun affecting marine life.

These effects need to be monitored and factored into the planning for the future of the estuary and the shellfish industry. Climate changes, along with those caused by other anthropogenic activities, can compound the impacts to estuaries (e.g., plant and animal species diversity, and species migrations and locations). Some anthropogenic changes may be modified– such as river flow patterns, river passage, siltation, agricultural run-off, and logging practices. But without significant national and global efforts to reduce greenhouse gases, we have little control over surface ocean temperatures, CO2 concentrations, or ocean acidification that have multiple down-stream impacts.

Climate change can no longer be ignored; effects are already being experienced and are affecting the future economic viability of the shellfish industry in Willapa Bay and Grays Harbor.

Increased Monitoring for Ecological Health

Review of different sampling and monitoring programs reveals the breadth and extent of monitoring that has been conducted over time by different entities. More often than not, however, regional monitoring efforts have been interrupted by loss of legislative funding resulting in partial short-term data sets that are therefore not conducive to measurement of long-term trends analysis required for regional climate change analysis.

There is a growing number of environmental and ocean monitoring programs, conducted by federal, state and local governments as well as educational and private institutions. These may not collect similar data, nor is it all readily accessible or comprehensible to the public. These programs need to be reviewed for consistency, overlap, accessibility, and applicability to long-term monitoring of the watersheds and the coast. There is already a planned west coast-wide (California, Oregon, and Washington) inventory and review of past and current monitoring programs addressing ocean acidification that is to identify gaps and monitoring needs. During the 2019 Pacific Coast Shellfish Growers Association meeting, the need for additional monitoring was identified by several entities. These efforts should be coordinated. Where possible, monitoring protocols should be coordinated to provide the greatest amount of comparable regional data from as many stations as possible to better inform the impacts of climate change, the status and health of the coast, and Willapa Bay and Grays Harbor estuaries in particular.

The Northwest Association of Networked Ocean Observing Systems (NANOOS) (see Appendix C) data portal appears to come closest to providing a “clearinghouse” for environmental monitoring results, and already includes data from government, tribal, educational, and private entities. If this is to serve as “the” clearinghouse and “go-to” portal for the data collected by multiple sources, content should be reviewed for inclusiveness, ease of access and use, and ease of understanding.

Additionally, there should be regular marine population surveys to map the changes in plant and animal species diversity, population, migration or displacement, changes in percentage of “lost bottom”; and density, location, and life stages of burrowing shrimp. This may require expanding the number of stations within the bay and offshore waters of the outer coast as well as coordination between the different monitoring and surveying entities.

It is imperative that long-term funding be dedicated to monitoring the inner bay and outer coast of both Willapa Bay and Grays Harbor. It is also imperative that the state agency or agencies, with the best expertise, be granted the legislative authority to manage the funding in the coastal ecosystem associated with regional climate change.

Farming Options

Aquaculture operating conditions and the regulatory environment are evolving as a result of climate change and increased concerns over ecosystem health. Market expectations, a growing interest in food production methods and sustainability, eco-labeling and certification, and/or new culture and food-safety requirements may also force industry to operate differently in the foreseeable future. Thus, modifications to current shellfish farming practices or adopting completely new methods of farming may be required.

New, forward-looking farming and harvesting options should be identified, considered, reviewed, and tested where possible. Floating systems, above and beyond the current long-line systems already identified in a previous section, should be examined. Surface and submersible pens or cages are being used to culture many species world-wide including shellfish. Extant systems are now capable of operating in high seas and, with modification, may have application for safe operation in waters safe from coastal storms, tsunamis, and earthquakes. New management and permitting approaches to large-scale operations may allow for smaller operators to participate in off-shore projects.

Land-based Systems

Land-based culture systems are typically a series of raceways, tanks, or other containers with seawater (or freshwater) being pumped through the system, either indoors or outdoors, and subject to controls and/or treatments at any step in the process. Land-based facilities can be constructed to operate as an “open” system with constant seawater input pumped from a bay or the ocean, filtered and/or treated before it enters the system, and once again filtered or treated before returning to the original source. “Closed” systems have an isolated closed circulating system that will require only small additional seawater additions to make up primarily for evaporative loss, etc. Water re-use can also be employed for conservation of heat within the systems.

These pumped seawater systems exert maximum control over waterflow and quality. They are considered to be one of the most versatile aquaculture systems, capable of controlling temperature of the culture water, light exposure, regulating pH (acidity), regulating flow, recycling and purifying waste-water. Light exposure in the culture container(s) can be regulated to emulate natural daylight periods as well as different light spectrum frequencies to manipulate growth and maturation rates.

These systems can be multi-use providing multiple options for land-based culture. Hatchery systems for bivalve spat production and setting on substrate are already well-known. It is also possible to control the time necessary to reach market-size in land-based facilities by controlling growth through feeding and thermal control of the rearing environment. They can also be used for the culture of multiple species in environmentally controlled seawater systems for shellfish culture. In the event of disease or infection, affected animals can be quarantined and treated in a culture container and isolated from other animals.

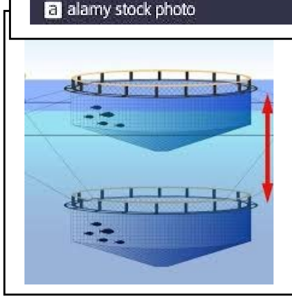
Land-based systems can be operated independent of the power grid using alternate energy sources such as solar or wind power. They can also be placed at higher elevations to avoid the impacts of possible tsunamis.

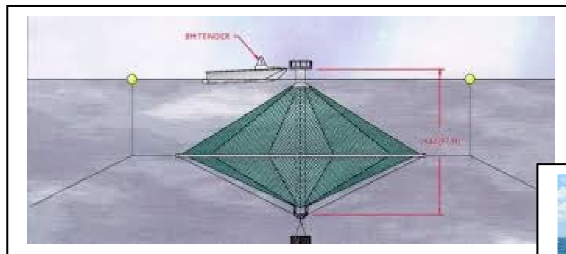
Marine Off-Shore Aquaculture

The majority of marine aquaculture operations globally are within a state's (or nation's) waters and near-shore. They include pens and rafts maintained at the surface with the cultured species continually submerged. Historically pens and rafts have been in protected coastal locations, in relatively shallow waters, and with easy access to port facilities. Over-crowding, inadequate regulations, and little understanding of the industry have resulted in mixed environmental effects depending on farm location, density of farms, ethos of the growers, and local regulations. As a result, acceptance of aquaculture has been mixed, and in some places there is a mistrust of the industry. Increased concerns over environmental impacts and food safety, however, have resulted in the development of best management practices for aquaculture, product certification schemes based on culture practices and food safety, and regulatory frameworks to ensure the continued sustainability of marine aquaculture.

There is increasing interest in locating marine aquaculture operations "off-shore" in U.S. federal waters (beyond three nautical miles) as these waters are generally deeper than coastal waters, situated in cleaner and more productive areas, less subject to agricultural run-off and other anthropogenic outfalls, less visible to coastal communities (creating less visual "pollution"), and present fewer conflicts over water use.

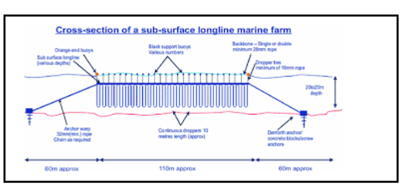
Deep-water aquaculture can be conducted using rafts and pens similar to those used in near-shore areas however new structures have been developed to better withstand the stresses of an unprotected off-shore environment and are available in many sizes and shapes.

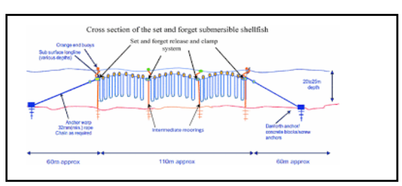


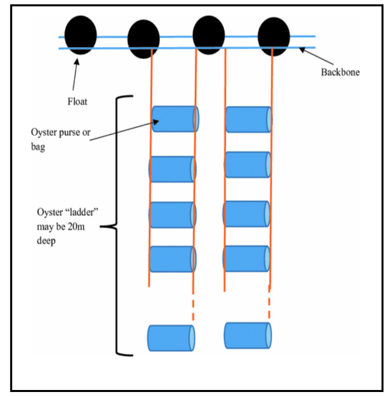


Today's enclosures can be maintained at the surface and partially submerged or completely submerged below the surface and off the sea-bed at all times. For servicing or harvest of the cultured product, the "container" can be raised to and partially above the surface to allow easy access from a vessel at the surface. Automatic feeders, remote environmental monitoring devices, and cameras can be incorporated into many structures. Submersible structures have been shown to be able to withstand intense and unusual weather events if they are properly deployed and tethered to the sea-bottom. New designs are being deployed throughout the world to accommodate different environments, species, and regulatory requirements.

New Zealand has specified areas five to twelve miles offshore, 35 to 50 meters deep, for shellfish culture. Long-line systems, suitable for an offshore environment are being developed and tested with longlines that can measure over two miles in length. Different methods of flotation are being evaluated in these designs.

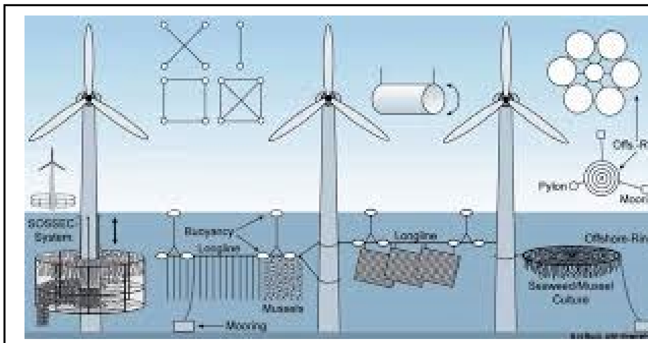




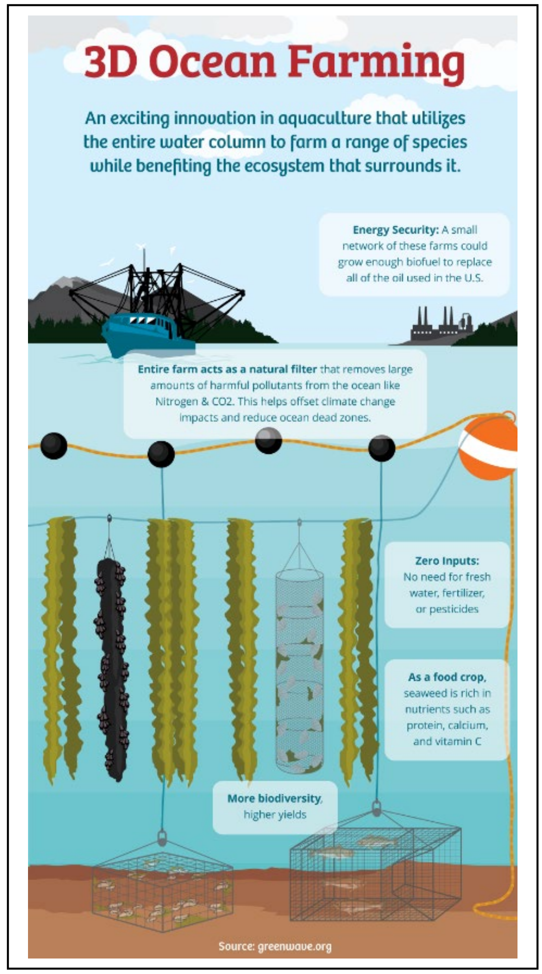


Specifically for oysters, a "ladder" system using oyster bags or purses is being evaluated for offshore deployment in New Zealand.

Another innovative approach to offshore aquaculture is to incorporate aquaculture into wind-farms that already have an infrastructure in place. Research into developing aquaculture in Germany's EEZ in the North Sea, in the German Bight, has been underway since 2000 when the first feasibility study was initiated. This schematic shows different types of aquaculture systems that could be used for a variety of species including finfish, shellfish, and algae or kelp. There remain many challenges for this type of project in the North Sea because of the complicated legal issues of international law, EU law, and German national law. Nevertheless, the concept of aquaculture linked to windpower structures continues to be examined. China announced the beginning of a windpower-aquaculture project in the Shandong area that is to be completed in 2021.



Integrated Multi-Trophic Systems (IMTA)



Certain practices can be adopted to minimize negative impacts of aquaculture and more readily address ecosystem goals. "Integrated multi-trophic aquaculture (IMTA) is the practice which combines, in the appropriate proportions, the cultivation of fed aquaculture species (e.g. finfish/shrimp) with organic extractive aquaculture species (e.g. shellfish/herbivorous fish) and inorganic extractive aquaculture species (e.g. seaweed) to create balanced systems for environmental sustainability (biomitigation), economic stability (product diversification and risk reduction), and social acceptability (better management practices)." (Soto, D., (ed.) 2009). This concept has been used in freshwater systems, particularly in Asia, as well as in the marine environment in both temperate and tropical waters. Research has and is being conducted in many countries including the United States, Canada, Chile, South Africa, China, Taiwan, EU countries, and in the Mediterranean. IMTA principles or concepts can be used in both land-based and open-water marine environments and may have applications in the Pacific Northwest for species including Pacific oysters or clams.

Benefits of integrated multi-trophic aquaculture above and beyond commercial product diversity, increased growth rates, and reduction of actual and perceived negative impacts of aquaculture, can include providing important ecosystem services such as uptake of CO_2 and reduction in ocean acidification. A workshop on IMTA was sponsored by the Pacific Aquaculture Caucus and Peninsula College in Port Angeles in 2010.

Regulatory and Management Considerations

The permitting process for aquaculture operations has frequently been regarded as the most difficult, complicated, and time-consuming phase of establishing an aquaculture project/operation. Permitting requirements vary depending on whether one is operating in federal waters (beyond three nautical miles) or in state waters; in some states, as in Washington, additional shoreline or county regulations may be applicable. It is also important to coordinate with local Tribes and the Northwest Indian Fisheries Commission. Certain federal agency requirements must be met in state waters as well.

Off-shore aquaculture can be defined in terms of distance from shore, depth, or current however there is no universally accepted consistent definition; for the purpose of this section off-shore refers to aquaculture in federal waters, beyond three nautical miles. The increased distance from shore may help mitigate any negative impacts that may be experienced in bays or nearshore.

One new approach to promoting, managing and permitting aquaculture is being developed by the Ventura Port District (VPD) in California whose aim is to build on their existing fishing industry and port, bring new sustainable fresh seafood to the region, and to support the local economy. The project is known as the Ventura Shellfish Enterprise (VSE) and includes a number of volunteer partners. The Port has taken on the responsibility of all preliminary pre-application work and application preparations. They have now submitted applications to the Army Corps of Engineers and the California Coastal Commission to farm mussels in a 2,000-acre area comprised of twenty 100-acre growing sites, in federal waters, approximately 3.5 miles from Ventura Harbor.

It was determined through the site selection process that locating in federal waters would interfere less with existing activities, minimize environmental impacts, limit visual pollution, and have less opposition. Several state water locations initially considered were rejected for a variety of reasons including conflicts with trawl grounds and marine sanctuaries. Moving to federal waters means that the Army Corps of Engineers is the primary permitting agency rather than the California Coastal Commission, which may facilitate the process.

The Port has received two NOAA grants through the National Sea Grant College Program to help with public education, website development, preparation of strategic permitting plans at the state and federal level, site selection, preliminary environmental monitoring, spatial planning, coordination with FDA to comply with National Shellfish Sanitation Program requirements, and follow-through on permit application questions and issues. The concept of a government entity (the Port) filing the initial permit application for federal waters, with the intent of subleasing or sub-permitting smaller areas, has never been done before. This however can make it possible for small operators to become involved in a project that would be financially prohibitive if they were responsible for all the initial permitting costs. The Port, however, can justify the effort as an investment in economic development. NOAA hopes to be able to use this as a model for other projects of this type in federal waters and is exploring the possibility of establishing a roadmap or process for other state or local governmental agencies to follow.

Education and Training

Education and training are the basic building blocks for maintaining vital communities that will persist into the future. Throughout the nation communities are reeling from changes in employment opportunities as a result of jobs moving offshore, mechanization, and market demands for products produced through increasingly “sustainable” and environmentally acceptable methods. In Washington, forest products industry closures had a major negative impact on employment and the economy of the affected communities.

In 2017 Pacific County had a median income of $39,895 and an 18.6% poverty rate with Grays Harbor County having a median income of $45,483 and a poverty rate of 16% while the numbers for Washington State were $70,979 and a 12.2% poverty rate. One way to improve these numbers for the coastal counties is to support and encourage the development of sustainable aquaculture through education and training.

Aquaculture is becoming increasingly important as a seafood source in the United States and globally as wild stock sources have plateaued and cannot be substantially increased without overfishing. According to FAO, nearly 50 percent of the world’s food fish comes from aquaculture. The United States ranks 17th in aquaculture production but, with over 95,000 miles of coastline and the largest exclusive economic zone, has the potential to be a leading global aquaculture producer. Many high value seafood products are being cultured in developing countries and provide year-round jobs in foreign coastal communities at the farm level as well as in the processing sector. These products are exported to developed countries such as the United States where consumers are willing and able to pay for these products.

Further reason for growing the U.S. marine aquaculture industry is that the United States relies heavily on seafood imports to meet domestic demand for a variety of species and products, from low to high value. A movement to consume products from “close-to-home” is gaining importance and can encourage consumption of domestically produced farmed seafood in place of imports.

Educational programs to train and prepare high school students and adults for a future in aquaculture and related careers have been established in other parts of the country, by different entities. Following are several examples for review and possible emulation or adoption in Washington.

Bridgeport Regional Aquaculture Science and Technology Education Center

The Aquaculture Center (see Appendix D) began in Connecticut in the late 1980s through coordinated efforts among regional eductors, local legislators, a statewide advisory committee, and agreement by the Bridgeport Board of Education to establish the Bridgeport Aquaculture Pilot Project. The Connecticut State Board of Education approved this be designated a Regional Vocational Aquaculture School in 1989. Subsequently through legislation and community support, funding was made available for school site location and building construction. First classes were held in February of 1993. In 2010 a 30,000 square-foot addition was opened.

The school now includes:

- aquaculture laboratory with marine and freshwater recirculating systems, micro-algae laboratory, pathology laboratory, and a greenhouse/hydroponics laboratory;
- several fishing/research vessels;
- computer-assisted design laboratory including a hydraulic training system as well as CAD/CAM and boat design workstations;
- boat construction laboratory;
- chemistry laboratory with sophisticated analytical equipment including an atomic absorption spectrophotometer (AAS), programmed-temperature gas chromatograph, infrared and ultraviolet/visible spectrophotometers, scanning electron microscope, mass spectrometer;
- Long Island grow-out systems with a summer farm for finfish, shellfish, and algae species; certified oyster and clam grounds; and a seaweed farm;
- Ship bridge simulator;
- Remotely operated vehicle (ROV);
- Video-conferencing equipment.

Students are prepared for working in aquaculture and allied industries and many move on to post-high school education.

Rhode Island Department of Labor and Training

The governor of Rhode Island invested heavily in training programs through the RI Department of Labor and Training after the 2008 recession. Curricula Planning Grants were made available to any groups who wanted to set up internship programs and had a need for employees. Since 2008 several programs have been developed with the involvement of Real Jobs Rhode Island, the East Coast Shellfish Growers Association, the Education Exchange, a 501 (c)3, and Sea Grant. Industry partners have been involved to help identify the industry employment and training needs and to provide internship possibilities. One of the challenges was the decision to pay students minimum wage during some parts of the training.

Among the training modules developed were team building, basic boating skills, shellfish biology and farming techniques, dealer and shipper skills, oyster shucking and basic food service requirements. They have now developed industry recognized credentials.

Climate change: Suggested research and action agenda

Monitoring

1. Review, catalog, and compare existing (state, federal, university, and private) monitoring and remote sensing systems for data coverage and accessibility;
2. Identify information gaps, as well as additional stations, that may be necessary for monitoring changing environmental conditions associated with climate change;
3. Improve upon and develop long-term monitoring systems and survey protocols to measure plant and animal life status including eelgrass coverage, burrowing shrimp populations and locations, and predator populations.
4. Develop a system and clearinghouse where all data can be easily accessed by the public.

Farming

1. Identify land-based and water sites for testing different culture methods including in the Willapa Reserves. Explore cooperation and coordination opportunities with NOAA Fisheries, NOAA Sea Grant, colleges, universities, and other entities.
2. Conduct/sponsor a 2020 workshop on Integrated Multi-Trophic Aquaculture with specific emphasis on conditions and applicability to Pacific and Grays Harbor Counties.
3. Review integrated multi-trophic aquaculture (IMTA) research being conducted elsewhere that is applicable to Washington coastal and estuarine land-based and marine environments.
4. Design pilot projects (land-based and on-water) for aquaculture practices not currently being used.
5. Explore the possibility of having a state or local government entity develop an offshore project similar to the Port of Ventura.

Education

1. Review high school curricula that have been developed in other states to teach high school students aquaculture concepts.
2. Establish a track resulting in specialized certification of aquaculture skills for high school students.
3. Develop a series of continuing education classes for adults, through either the high school or Grays Harbor Community College to provide basic understanding of aquaculture principles and basic technology.
4. Develop a certification program for veterans.

Timeline

March 2018

- Contact DNR
    - Extend desire to form team of engineers and scientists to solve the seemingly intractable problem of controlling ghost shrimp w/o chemicals
    - DNR expressed interest to discuss our participation

April – July

- Formed Griffin Team
- Started research into science, past concepts, oyster farming etc and begin ideation on design concepts

August 29

- Meet at DNR with online Partnership Working Group (PWG) - growers, DNR, scientists
    - Introduce our team
    - Explain our design methodology and strategies e.g. biological, mechanical/electrical/geophysical, chemical (non-chemical) , and hybrids
    - Listen/respond to questions, concerns and suggestions

August 30

- 1st complete Griffin Team meeting to define scope and basic concepts for proposal

September 13

- Submit Griffin Team Proposal to DNR
    - Three phases: Concept Designs, Proof of Concepts, and Monitoring and Testing
    - Ready to begin as soon as October 1 2018

- Inquiry from DNR: They have also interviewed DR Jackson Gross, toxicologist from UC Davis. Griffin Team willing to collaborate as directed by DNR.

October 10

- Updated Proposal submitted to DNR

    Step 1 :   WHAT TO DO and WHAT NOT TO DO

    - *Ghost Shrimp Control in Willapa Bay and Grays Harbor - Alternative Control Strategies and Constraints. This report would lay out the best-case scenario and design goals from the oyster growers and DNR's perspective.*

<u>*Step 2 : HOW TO DO IT*</u>

- *Ghost Shrimp Control in Willapa Bay and Grays Harbor - Report 2 of 3: - Practical Alternatives to Insecticide Spray. A comprehensive report presentation of all known and new concepts that meet the agreed upon design goals.*

<u>*Step 3 : DOES IT WORK*</u>

- *Ghost Shrimp Control in Willapa Bay and Grays Harbor – Report 3 of 3: - Building and Monitoring Selected Alternatives. A plan including the production, testing, and monitoring of those alternatives selected by the growers.*

- Telecom with DR Gross

  Dr. Gross chose not to participate or collaborate.

October 17

PWG review of the Griffin Team and J Gross proposals. Griffin Team chosen to proceed.

December

DNR assures the Griffin Team that the contract is worked out and a mid- January meeting with PWG is desired.

Pre-contract self-funded internal educational effort at Griffin Team.

- Annotative bibliography concerning Ghost Shrimp and Shell Fish Ecology and Control Methods
- Stage 1 Report: The Impacts of Ghost Shrimp on Oyster Culture in Willapa Bay and Potential Control Methods

  Introduction
  Background of the Problem
  Effects on the Oyster Industry
  Ghost Shrimp Ecology
  Oyster Ecology
  Oyster Operations
  Review of Past Shrimp Mitigation Strategies and Concepts
  Oceanography

Early January

Notified that no contract forthcoming until Griffin Team attends a Pre-Contract Meeting/Interview with PWG.

January 29

Pre-Contract Meeting with PWG in Raymond, WA.

February 28

Revised Proposal submitted to DNR

- The growers' cooperation and willingness to share both their urgency and long-term vision led to a revision of the Griffin Team proposal
  - Concepts focusing on "Stop the Bleeding" strategies to reduce bed and production losses.
  - Concepts toward a more balanced traditional or modified bed culture.
  - Concepts toward a stable and environmentally sustainable industry and community.

April 4

Griffin Team Contract with DNR executed

Weeks of April 8th and April 15th

Meetings and field trips in Willapa Bay with growers, DNR and scientists.

May 2

Progress Report 1 submitted

- Research Focus
- Strategy
- Methods
- Research Needs and Recommendations
- Project Timeline

June 17-18

- Meetings with Growers in Willapa Bay
- POC Roller tests in Willapa Bay

July

Progress Report 2 submitted

- Phase 1 - Concepts based on Bed Conditioning Methods
- Phase 2 - Concepts based on Shellfish Farming Operations
- Phase 3 - Concepts based on Ecosystem Rehabilitation

August 8th

Meeting with PWG re Progress Report 2

- Goals, Approach, Promising Concepts
- Questions, Concerns and Suggestions

September 24th

Final Report draft for review submitted to DNR

October 7th

Final Report (Version 1.3) submitted to DNR

(end of timeline)

Team members

Team Co-Lead and Marine Machinery Engineer: Barry Griffin, BA Griffin Associates, Inc., Boston, Mass. /Bainbridge Island, WA

Team Co-Lead and Civil/Structural Engineer: Robert Shulock, PE. Bainbridge Structures Group, llc., Bainbridge Island, WA

Aquatic Fisheries Biologist: Dr. Conrad Mahnken, PhD, Aquatic Resources Consultants, Bainbridge Island, WA

Marine Geophysicist and Engineer: Mike Williamson, Williamson Associates, Inc. Seattle, WA.

Naval Architect and Engineer: Jonathan Parrott, PE: Senior Naval Architect , Jensen Naval Architects and Marine Engineers, Seattle, WA.

Aquaculture and Fishing Gear Engineer: Gary Loverich, Bainbridge Island, WA

Aquaculture Scientist: Linda Chaves, Mercer Island, WA

Research Scientist and Editor: Marina Heppenstall, MS, Bainbridge Island, WA

Acknowledgments

The Griffin Team would like to acknowledge the following groups and individuals for their contributions:

To DNR administrators and scientists, with special thanks to Gabe Kaemingk for his leadership, balance, and positive attitude.

To PWG members, including the growers, scientists, and advocates – all of whom laid their passion, knowledge, and concerns on the table.

To David Beugli (WGHOGA) for his open exchange of information, contacts, and knowledge of the industry.

To Marina Heppenstall, whose detailed early research and editing led us quickly to the best way to approach the science needed to support the initial design thinking.

Appendix A - Selection of Eelgrass Transplantation Methods

Puget Sound Washington Department of Natural Resources (DNR)

Following is a listing of four planting techniques being tested by DNR to re-establish eelgrass beds in Puget Sound (*"Studies show challenges for eelgrass restoration" by C. Dunagan. 9/06/2018).*

- **Staples:** The plants are pushed into the substrate and anchored in place with 8-inch long landscape staples. This is the quickest method, but also the least secure of the methods under study.
- **Metal washers**: Plants are tied with hemp cord to round fender washers. 1 ¾ -inch across. The heavy washers can be dropped from boats to speed up the planting process. The hemp cord eventually degrades and detaches once the transplants are established.
- **Rebar**: Up to 25 plants can be attached with degradable hemp cord to a steel rod. Preparations take longer, but under favorable conditions the result is a closely spaced group of plants.
- **Burlap mat**: When burrowing shrimp are a problem, eelgrass shoots can be pushed through a piece of burlap, forming a mat that stimulates the dense growth of rhizomes. Burrowing shrimp cannot break through, so they tend to avoid the planted area. Eventually, the burlap degrades completely. This technique is the most time-consuming of all, both in preparation and in staking the mats to the bottom, but it may be the most successful under problematic conditions.

California Estuaries (Castorani et al. 2014)

- **Staples**: Eelgrass with intact rhizomes was anchored with bamboo V-shaped staples into plots with burrowing shrimp. The project was designed to test the hypothesis that planting eelgrass in an area with burrowing shrimp will cause the shrimp to vacate the area.

Pusan, Republic of Korea Department of Biology, Pusan National University, (Park JI, et al. 2007)

- **Staples** (77-94% survival rate)
- **Transplanting Eelgrass Remotely with Frame Systems (TERFS):** Eelgrass shoots are attached to a mesh metal frame using biodegradable "string". The frames are placed on the bottom; the shoots will root in the sediment while the string biodegrades. The frames must be removed after the shoots have rooted and before they have grown over the frame. (59-69% survival rate)
- **Shell Method**: Oyster shells are used as an anchoring device for eelgrass and rhizomes.(81.3% survival in muddy sediment; 76.5% in silty sediment; 5% in sandy sediment)

Qingdao, China (Zhou Y et al.2014)

- **Stone-anchoring (buried)**: Several rhizomes of rooted shoots were bound to a small elongate stone with biodegradable thread (cotton or hemp) and then the "bound packet" was buried at an angle at a depth of 2-4 cm in the sediment. Three-month survivorship was >95%
- **Stone-anchoring (surfac**e): Same preparation as above but not buried – just placed on the surface. Two-month survivorship was ~83%.
- After 2-3 years for both methods, shoot height and biomass was similar to nearby natural populations.

Cornell University Cooperative Extension (CCE) – Long Island

- **Seeding:** Requires collection of seeds from live flowering plants in the summer and separation from the shoots which die after flowering. They must then be maintained in tanks and allowed to mature. Once the seeds have matured, they may be broadcast over the planting area. Otherwise seeds may be allowed to mature into plants and then planted when they reach an optimal size.
- **Buoy Deployed Seeding (BuDS)**: The harvested flower shoots are placed into a pearl net which is attached to a buoy. This is then anchored at the site where seeding is to take place. The flower shoots then drop the seeds naturally as they develop.
- **Free planting**: In some cases it's possible to push the rhizomes into the sediment, deeper than it would normally occur, and at a 45^{o} angle.
- **Rock**-**planting**: 3-10 shoots are placed in a depression in the sediment and a grapefruit-sized rock is placed on them to keep them in place. Smaller and larger rocks have been used. Shoots will root and eventually grow away from the rock.
- **TERFS**: (see above)

Chesapeake Bay (Orth, Robert KJ. Et al.1999)

- **Unanchored, hand planting**: Unanchored shoots with rhizomes were planted into the sediment at an angle to a depth of between 25-55 mm. First month survivorship 73%.

Rhode Island (Granger et al 2002) – University of Rhode Island

- **Seeding:** Seeds are encased in Knox gelatin matrix to prevent or reduce seed predation and loss of seeds from waves and currents. Seeds are injected into the sediment by a food processing pump that is mounted on a sled, being pulled by a boat. A flange mounted on the boat then covers the seed with an inch of sediment.

Appendix B – Natural predators of burrowing shrimp

Pacific staghorn sculpin (*Leptocottus armatus*)

Pacific staghorn sculpin is the most abundant sculpin in Washington state and in Grays Harbor, occupying pelagic to surface waters as habitat. In Grays Harbor they were found to be the most abundant and widely distributed marine fish. Staghorns are probably as numerous in Willapa Bay. Moon Island Flats in Grays Harbor is possibly a nursery area based on observations of small sculpins residing there. The staghorn sculpin population is stable. Stomach contents of the sculpin from many areas have shown the presence of burrowing shrimp (*N. californiensis)*; in one study (Armstrong et al.1995), the staghorn sculpin summer diet in Grays Harbor was shown to be comprised 27 percent by *N. californiensis*, and 6 percent by the mud shrimp *Upogebia pugettensis*. While the sculpin's diet varies throughout the year, burrowing shrimp (*N.* californiensis) are an important contributor to sculpin diet and appear frequently in stomach samples.

Sturgeon

Green sturgeon (*Acipenser medirostris* and white sturgeon (*A. transmontanus*) are frequent inhabitants of coastal estuaries from northern California to British Columbia. Analysis of stomach contents from 95 commercially landed green sturgeon and six white sturgeon commercially landed in the Willapa Bay, Grays Harbor, and Columbia River estuary from 2000 to 2005 revealed that 17 to 97 percent had fish food items in their gut and had fed predominantly on benthic food items and fish. Burrowing shrimp were also important food items for both white and especially green sturgeon taken in Willapa Bay during the summer of 2003.

In a 2008 paper, Dumbauld and co-authors noted that both green and white sturgeon were frequent inhabitants of coastal estuaries and that they may have had a significant role in controlling burrowing shrimp populations. He has also suggested that stock enhancement programs for sturgeon and other predator species could help control burrowing shrimp populations.

Green sturgeon

There are two genetically distinct stocks of green sturgeon, the northern Distinct Population Segment (nDPS) and the southern Distinct Population Segment (sDPS) both of which range from California to British Columbia. Of the two stocks, the sDPS has been the predominant green sturgeon stock in Willapa Bay originating primarily from the Sacramento River, while the nDPS originates in the Klamath and Rogue Rivers in Oregon.

The North American Green Sturgeon, reportedly once a significant predator of burrowing shrimp, has experienced decreases in population size. The sDPS was listed as “threatened” under the Endangered Species Act in 2006, with specific threats to adult and sub-adult sturgeon identified in both Willapa Bay and Grays Harbor. The nDPS has been given the status of a “species of concern”.

The sDPS green sturgeon recovery program goal and objective is to be met by “reducing threats associated with habitat degradation and access, contaminants, and take” (NMFS. 2018). No hatchery intervention is proposed. As such, the recovery program will take many decades to show results; even with a hatchery program, recovery would be lengthy due to their extended life history, not reaching sexual maturity until around age 15 and living to 60-70 years of age.

There are a number of papers regarding green sturgeon nDPS and sDPS stock origins and genetics; one mentions the possibility that the Columbia River may serve as alternative spawning habitat as climate change occurs. This needs to be further investigated, especially if a hatchery program is to be considered.

White Sturgeon

These anadromous fish spend much of their life in fresh water and are slow- growing with females attaining maturation in 11-34 years and males in 11-22 years.   In the Chehalis River, spawning probably occurs in early summer. In Willapa Bay it is believed that the white sturgeon move upstream in late winter or early spring. They are known to move between Grays Harbor and the Columbia River. However, it is not known whether they actually spawn in Grays Harbor tributaries.

Migration in the marine environment does not appear to be frequent or of great distance, due perhaps to the species preference for low-salinity fresh water.

Foods of juvenile white sturgeon include insect larvae and mysids, while adults eat sculpins, stickleback, lampreys, small sturgeon, crayfish, molluscs, crangon shrimp, ghost shrimp, and flatfish. In Grays Harbor, sturgeon feed on salmon carcasses.

White sturgeon seem to prefer bottom types of mud and sand in low salinity marine and estuarine waters.

The center of distribution for the white sturgeon is the Columbia River with smaller populations in Grays Harbor and Willapa Bay. These populations, however, are declining with Willapa Bay white sturgeon limited to the Willapa and Naselle River areas, yet some are still seen in the Bay throughout the year.

Salmon species: **A word of caution**

Pacific salmon occur in coastal streams and rivers of Washington; at least three species, chinook, coho and chum salmon are part-time residents in Willapa Bay and Grays Harbor and are important in both commercial and recreational fisheries. All three species are maintained at least in part through coastal hatchery supplementation in hatcheries located in Grays Harbor and Willapa Bay watersheds.

Concern has been expressed regarding increasing the number and abundance of large marine fish predators in coastal bays and their impact on native salmonids, especially coastal chum salmon juveniles that require varying periods of estuarine residence during their juvenile migration to the sea. Chum salmon adults return to the bays at a size well-able to fend for themselves from other fish predators, at a size range of approximately 70-80 cm fork length. It is with the smaller juvenile chum and chinook salmon that forage in the coastal bays for extended periods that concerns have been raised especially in situations of reduced eelgrass meadows that provide cover and protection for juvenile salmonids.

Owing to their anadromous migration as juveniles at a small size, Pacific salmon are probably not major benthic predators and unlikely to contribute in any major way to predation of burrowing shrimp except perhaps during feeding on larval stage shrimp in the water column, as reported in Tilamook Bay, Oregon in the 1970s, or in their later migratory stages of development.

Except for sea-run cutthroat, the relatively short fresh-water residency time of chum, coho, and chinook limits the contribution that these species could make as predators of burrowing shrimp. Studies of salmonid stomach contents also indicate that migratory juvenile salmon are not preying on burrowing shrimp. It is not clear what juvenile salmon feed on as they migrate out of larger river systems as only a few studies have been documented.

In the near-shore waters of British Columbia, the diet of chum salmon is dominated by Harpacticoid and Gammarid amphipods. A single Harpacticoid species was found to be almost exclusively the major prey item in the Nanaimo River estuary. In Hood Canal, as juvenile chum salmon begin to enter seawater in late spring, their preferred food appears to be epibenthic and neritic zooplankton. In near-shore waters of Puget Sound, migratory juveniles also feed on epibenthic and neritic zooplankton though their diet is dominated by copepods and Harpacticoids. As food sources decline in the summer, juvenile chum salmon move offshore and the food source changes to larger pelagic and nektonic organisms; and may indicate that the salmon juveniles have obtained a body size that would allow predation on burrowing shrimp.

Survival of out-migrating juvenile salmon in the bays in the presence of an increased predator base is complicated because so little of their estuarine life history is known. As with other salmonids, too little is known about their migratory and predatory habits to reach any realistic conclusions on the behavior of native salmonids in the presence of an increased predator base. However, care should be taken to protect these genetically unique coastal stocks, none of which have been listed under the US Endangered Species Act. The potential negative impact of introducing aquatic predators to Willapa and Grays Harbor estuaries, in the absence of protective eel-grass, should be considered as a potential threat to our native salmonids.

Dungeness Crab

Dungeness crab, a predator of burrowing shrimp, are themselves prey to other predators of burrowing shrimp, notably staghorn sculpins. Without the safety of protective habitat such as eelgrass they are extremely vulnerable to predation by sculpin, even to the extent of impacting crab year-class strength in coastal estuaries (Armstrong, Janet L. et al. 1995). It is possible that, with greater protective eelgrass cover, they could be more efficient predators of burrowing shrimp.

Gray Whales

Gray whales *(Eschrichtius robustus)* are the largest predator of burrowing shrimp in Washington waters. In the spring most gray whales migrate north, past Washington, to their primary feeding grounds in the Arctic. According to the Cascadia Research Collective, an average of ten will typically feed in the Whidbey Island area; there is also a “Pacific Coast Feeding Group” of about 200 that feed in Pacific Northwest waters through the summer and fall. Some have been known to enter Willapa Bay where they will consume burrowing shrimp.

In a census, based on satellite imagery of mud flats, it was estimated that gray whales consumed up to 300 metric tons while feeding in the delta of the Snohomish River.

Appendix C – Northwest Association of Networked Ocean Observing Systems

www.nanoos.org

The Northwest Association of Networked Ocean Observing Systems (NANOOS) is the Regional Association of the national Integrated Ocean Observing System (IOOS) in the Pacific Northwest, primarily Washington and Oregon. NANOOS has strong ties with the observing programs in Alaska and British Columbia through our common purpose and the occasional overlap of data and products.

Ocean Observing has become a system for observations, modeling and analysis of marine and ocean parameters that support operational ocean activities such as fisheries, recreational boating, natural hazards warnings, search and rescue operations, and marine operations, as well as scientific inquiry. Through an ocean observing system these diverse user groups can receive accurate descriptions of the present state of the oceans including living resources, continuous forecast of future sea conditions, and forecast indicators for climate change.

A Coastal Ocean Observing System is designed to produce and disseminate ocean observations and related products in a common format and according to sound scientific practice. The Coastal Ocean encompasses the region from the head of the tide to the seaward boundary of the Exclusive Economic Zone or EEZ, which is a seazone where states have special rights over the exploration and use of marine resources.

Coastal regions including the Great Lakes form a partnership that's linked to users via an interactive flow of data and information, which is first measured and transmitted, then organized, cataloged, and disseminated, and finally translated into products that meet users' needs and requirements. A management oversight system insures the continued and routine flow of data and information as well as the ongoing adaptation to user groups with the development of new technologies.

Regional Coastal Observing Systems

Alaska
Caribbean
Central and Northern California
Great Lakes
Gulf of Mexico
Pacific Islands
Mid-Atlantic
Atlantic-Northeast
Pacific Northwest
Southern California
Atlantic Southeast

National Observing System Partners

IOOS Association
Alliance for Coastal Technologies (ACT
Southeastern Universities Research Association (SURA)

Integrated Ocean Observing System IOOS

Appendix D - Bridgeport Regional Aquaculture Center

(Following text taken directly from the website)

The Aquaculture Center serves a community of diverse students with a broad range of social, economic, cultural and ethnic backgrounds who bring to the school a variety of skills, talents and learning styles. We offer students from school systems in the greater Bridgeport region the opportunity to enhance the traditional academic high school curriculum with a specialized emphasis on science and technology instruction as related to the development of aquaculture in the State of Connecticut.

The Concept

The concept of establishing an aquaculture school in Bridgeport was the result of years of collaboration among regional educators, local legislators and statewide advisory committee members. These efforts resulted in a **Special Act of the Legislature which provided for the construction of this highly technological facility.**

Mission Statement

The mission of the The Bridgeport Regional Aquaculture Science & Technology Education Center is to provide a rigorous educational program which ensures that students are able to examine problems and make informed decisions concerning society's relationship with the aquatic environment. The Aquaculture Center serves a community of diverse students with a broad range of social, economic, cultural and ethnic backgrounds who bring to the school a variety of skills, talents and learning styles. We offer students from school systems in the greater Bridgeport region the opportunity to enhance the traditional academic high school curriculum with a specialized emphasis on science and technology instruction as related to the development of aquaculture in the State of Connecticut. The educational program is designed to provide students with learning experiences developed in collaboration with industry, government agencies, post-secondary educational institutions and community organizations from local municipalities. Our goal is to enable students to meet rigorous academic standards through selected educational experiences that require them to work with technologies used by professionals in the maritime industry and aquatic research community. The Aquaculture School has, and will strive to maintain, a unique educational program that is relevant, focused, innovative and continually evolving with an emphasis on high academic standards that will enable students to meet the needs of a changing world.

*Approved by the Bridgeport Board of Education at a meeting held on Monday, November 27, 2000

Philosophy

It is the philosophy of the Bridgeport Regional Aquaculture Science & Technology Education Center that we provide an equal opportunity for the continued growth and development of our students. The staff believes that we must provide a supportive learning environment where students are encouraged to appreciate and respect all people, work cooperatively and strive to become contributing citizens of society. We believe that we must educate our students to be environmentally aware and to understand the relationship of man's actions and their impact on the environment to foster an appreciation of the value of living things. We believe that our students must learn to be capable problem solvers, rational decision-makers and critical thinkers in order to be beneficial contributors to their communities. We recognize that in our changing society, it is necessary to study, on an ongoing basis, the needs of youth and to reflect these changing needs in the implementation of our evolving curriculum.

Initial Funding (1988-1989)

In 1988 and again in 1989, the Bridgeport Board of Education applied for and received two competitive grants totaling $100,000. Also, in 1989, a Special Act of the State Legislature approved $20,000 for supplies in support of the Bridgeport Aquaculture Pilot Project. The Connecticut State Board of Education approved the Bridgeport Board of Education’s request to be **designated a Regional Vocational Aquaculture School**. Testimony in support of the Aquaculture school, presented in a collaborative effort by the Connecticut Sea Grant Program as well as commercial and recreational marine industries, focused upon the need to develop marketable skills for students.

Building the School (1991-1993)

Plans for building the Bridgeport Regional Vocational Aquaculture School began when the Connecticut State Board of Education approved the Bridgeport Board of Education’s request to be designated as a Regional Vocational Aquaculture School on April 5, 1989. House Bill 5717, An Act Concerning a Regional High School for the Study of Aquaculture, provided the direct state funding of seven and one-half million dollars for the building of the school. A site selection report identified Captain’s Cove Seaport as a logical site for a program of this type. Thanks to the cooperation of Mr. Kaye Williams, President of Captain's Cove Seaport, Inc., sufficient space was found at the Cove and construction plans were finalized. Groundbreaking for the facility took place in December of 1991, and the first classes were held in the new facility in February of 1993.

Renovations & Expansion (2010)

We are passionate about ensuring your future through educational innovation and opportunities for personal and academic discovery. As a result of years of instructional vision, as well as diligent planning, our already-unparalleled institution opened its 30,000 square-foot addition in August, 2010. The new wing to the existing facility includes an aquaculture hatchery/grow-out laboratory equal to that of a research or commercial facility, a seafood science classroom that, by day, will provide certificate instruction in seafood handling and preparation; in the after school hours, a seafood outlet and a culinary demonstration area where students will work alongside notable, professional chefs as they prepare seafood for invited members of our community are also planned. Further additions include innovative chemistry, biotechnology and aquaculture laboratories, a resource center designed to provide students with unlimited access to information as well as serving as a support site for guest speakers presenting topics concerning environmental awareness and global concerns. Also included are new interactive teaching classrooms with advanced computerized technology for instructors, as well as students, to utilize.

Improvements to the original building include the meteorology laboratory, video conference room, career center and the aquaculture technology education instructional areas. With the combination of progressive initiatives, existing-facility improvements and plant expansion, we have the necessary tools for an enhanced, dynamic secondary school experience unequalled anywhere! While this new technology can amplify the delivery of educational material, we believe it is the professional, experienced and enthusiastic teaching staff at BRASTEC that propels our program to the next level. Our alumni have attended prominent colleges, universities, maritime academies and technical institutions throughout the country and beyond, attributing much of their success to the exemplary education received at this school. Together, you and our staff will explore the numerous, diverse career opportunities that are available in the aquatic, chemical, physical sciences and technology fields of endeavor, while developing the skills required to graduate college-ready and prepared to succeed in one's life work.

Our Facilities

The facility provides students with specialized laboratories and classrooms that compliment the marine-related curriculum of the school. Examples include a seafood science laboratory, an aquaculture finfish/shellfish lab, a marine construction shop, a marine propulsion and electronics lab and a computer-assisted design and drafting lab. The school also contains a modern telecommunications system capable of several educational functions including a computer network and a remote visual display system.

In addition, the school has a 56-foot research vessel, the Catherine Moore. The boat has the capability for classroom instruction, boat navigation and fishing operations to occur simultaneously. The activities aboard the Catherine Moore provide students with the opportunity to conduct marine biology, chemistry and ecological experiments, to engage in commercial fishing techniques and learn on-board navigation and marine electronic communication techniques. To compliment the Catherine Moore, the school operates smaller vessels for training and farm site maintenance.

Our Students

Our student body consists of students from Bridgeport, Fairfield, Milford, Monroe, Shelton, Stratford, and Trumbull. Our enrollment reflects a successful and cooperative effort by the participating school systems. The quality and diversity of curriculum, program activities and specialized facilities that our school has to offer serves as the blueprint for future school choice programs.

FFA *(Formerly known as Future Farmers of America – now just FFA)*

The FFA is a vital component of the aquaculture education program. It provides opportunities for students to develop personal leadership skills and to participate in career development activities while making positive contributions to their local community. Students are strongly encouraged to become members of the Bridgeport Aquaculture FFA, a chapter of the National FFA Organization.

A program of activities is developed each year by elected student officers and instructors who serve as advisors. Emphasis is placed on planning activities which allow members to strengthen life skills such as organization, interpersonal communication, extemporaneous and prepared public speaking, goal setting, teamwork and business meeting protocols.

Members enjoy participating in activities during school such as public speaking events, chapter business meetings, field trips and fund-raising. Team competitions with area FFA chapters are available to all members and are intended to promote sportsmanship and positive self- esteem in our members while demonstrating their knowledge of aquaculture related topics. The year is culminated with an annual awards event in the spring, where student members are recognized for their efforts.

Another important benefit for members is the Aquaculture School's FFA scholarship, awarded to students who have demonstrated leadership skills and the financial need for the award. Mailed to each member's home is the

FFA's official publication, "FFA New Horizons". It highlights information on aquaculture education, careers, FFA and new agricultural/ aquacultural developments as well as various youth-related topics.

Supervised Aquaculture Experience (SAE)

SAE is a required component of the aquaculture curriculum. It is an introduction to career awareness that goes beyond the regular classroom to provide additional aquaculture-related experiences. Students will be assigned a teacher who will assist the student with choosing an option. These options will enable students to apply what is learned at our school to an outside program or job that can possibly develop into a future career opportunity.

Unique Facilities

Our school provides students access to classrooms and laboratories equipped with the most modern equipment available Current highlights include:

Aquaculture Laboratory

- Marine & freshwater recirculating systems
- Micro-algae Laboratory
- Greenhouse/Hydroponics Lab
- Pathology Laboratory
- FloCam - Rapid Cell Counting and Identification

Research Vessels

- M/V Catherine Moore - 57-foot research vessel with on-board classroom
- Parker - 25 foot fishing boat
- Privateer - 25 foot Lobster boat
- Kevlar Cat - Multi-Hull training vessel

Computer Assisted Design Laboratory

- Hydraulic training system
- CAD/CAM and boat design workstations
- 3-D Printer

Boat Construction Laboratory

- Computer-aided machining station
- Commercial woodworking/boat building equipment
- Computer controlled machining table

Chemistry II Laboratory

- Atomic Absorption Spectrophotometer
- Programmed-temperature Gas Chromatograph
- Infrared & Ultraviolet/Visible Spectrophotometers

- Scanning Electron Microscope
- Computer-enhanced instructional stations
- Elemental Analyzer
- Mercury Analyzer
- Mass Spectrometer

Long Island Sound Grow-out Systems

- Summer Farm - used for the demonstration growout of selected finfish, shellfish and algae species
- Shellfish grounds - Certified areas for the production of oysters and clams
- Seaweed Farm

Bridge Simulator

- A fully interactive replication of the controls and maneuvering of various ships, including the Catherine Moore

ROV

- Remotely Operated Vehicle for underwater exploration, recoveries, inspections, search and rescue

Video-Conferencing Equipment

- Distance Learning and Communication studios

Bridgeport Aquaculture College Alliance (BACA)

The goal of the BACA Program is to offer students the practical knowledge and skills necessary to pursue either employment in the marine environment or a smooth transition to the many post-secondary educational available.

The BACA Program is designed primarily for 12th grade students who have expressed a desire for a concentrated, interdisciplinary approach to aquaculture education. Students will be responsible for the practical application of principles and concepts of biology, chemistry, physics, math, history, earth science and astronomy as it relates to aquaculture. Students enrolled in the BACA Program are awarded up to 5 (five) credits. The integrated course of studies offers an in -depth study of aquaculture to include the origins of aquaculture (history), aquatic ecosystems, (math and science), aquaculture engineering (math, science and technology) and survey and analysis (math and science). The activities of the program are enhanced by the use of the research vessel, M/V Catherine Moore.

Students are involved in a great variety of projects. They will have the opportunity to work side-by-side with marine scientists, business people and representatives from institutions of higher learning, both local and international.Computers are used to develop research skills, data collection and interpretation and to develop student- generated presentations for meetings and conferences.

Field trips to various sites are an integral part of the reinforcement of the principles learned in class. Many internships become available to BACA students during the school year. The Norwalk Maritime Museum, the Milford NOAA laboratory, the University of Connecticut and Aquarion have offered these internships in the past.

The Aquaculture Experience

What Is Aquaculture?

Our students have the unique opportunity to be a part of the exciting and expanding field of aquaculture. What is aquaculture? Aquaculture, as defined by the Food and Agriculture Organization (FAO) of the United Nations, is "the farming of aquatic organisms, including fish, mollusks, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding and protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated..."

Why is aquaculture so important? The following statistics should help explain:

- Demand continues to grow as more Americans seek the health benefits of eating seafood.
- The United States may need to import as much as 4 million tons of seafood by 2025, based on demand and population growth projections.
- A 2009 study made by Stanford University, 50% of the world's aquatic organisms consumed are farmed products.
- Fully 70% of the world's conventional commercial species are now fully exploited, depleted, or recovering from depletion.
- Growing demand for seafood creates an enormous opportunity for economic growth and new jobs in the U.S. aquaculture industry.
- Green technologies need to be developed to make aquaculture production more environmentally friendly.

These statistics clearly indicate the need for a properly trained work force. The Aquaculture Center's curriculum is designed to help students begin this process.

Appendix E – Partial list of Willapa Bay Workboats

Willapa Bay Ghost Shrimp Project
Vessel Data

Vessel	Owner	Length (ft)	Beam (ft)	Depth (ft)	Draft (in)	Open Deck ft)	Power (hp)	Prop (in)	Estimated BP (pounds)	Engine Type
KATHLEEN N	Nisbet	50	15	4.3	26	24 x 14	225?	26 x ?	3000	inboard
STANVIC	Nisbet	41	13.75	3	42	?	200?	30 x 14	2500	inboard
NANCY N	Nisbet	45	16.42	4.42	46	28 x 17	350	32 x 24	4000	inboard
CHETLO HARBOR	Herrold Fish & Oyster	56	16	5	42	30 x 15	330	36 x ?	4000	inboard
SYLVIA	Herrold Fish & Oyster	43	15	2.4	12	20 x 14	211	26 x ?	2750	inboard
Crew Skiff	Northern Oyster	20	7		48	8 x 6.5	200	10" x ?	1750	outboard motor
SEA LAND	Northern Oyster	21	9		48	8 x 8	225	10"	1850	outboard motor
NORTHERN	Northern Oyster	58	18		36 to 84	15 x 20	2 x 400	?	12000	inboard
MARI LEE	Northern Oyster	60	18		42 to 90	25 17	330	?	4950	inboard
NANCOTTA QUEEN	Northern Oyster	42	20		60	42 x 20	NA	NA	NA	barge

(End of Document)