Mechanical and Ecological Control of Burrowing Ghost Shrimp

including

Forward looking concepts for shellfish farming in Washington State

Summary of 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)

Contract No. 93-098786

Introduction

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.

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.

Summary of concepts and recommendations

Summary of objectives and concepts

This report recommends concepts and designs that will reduce burrowing shrimp populations in phases.

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.

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.

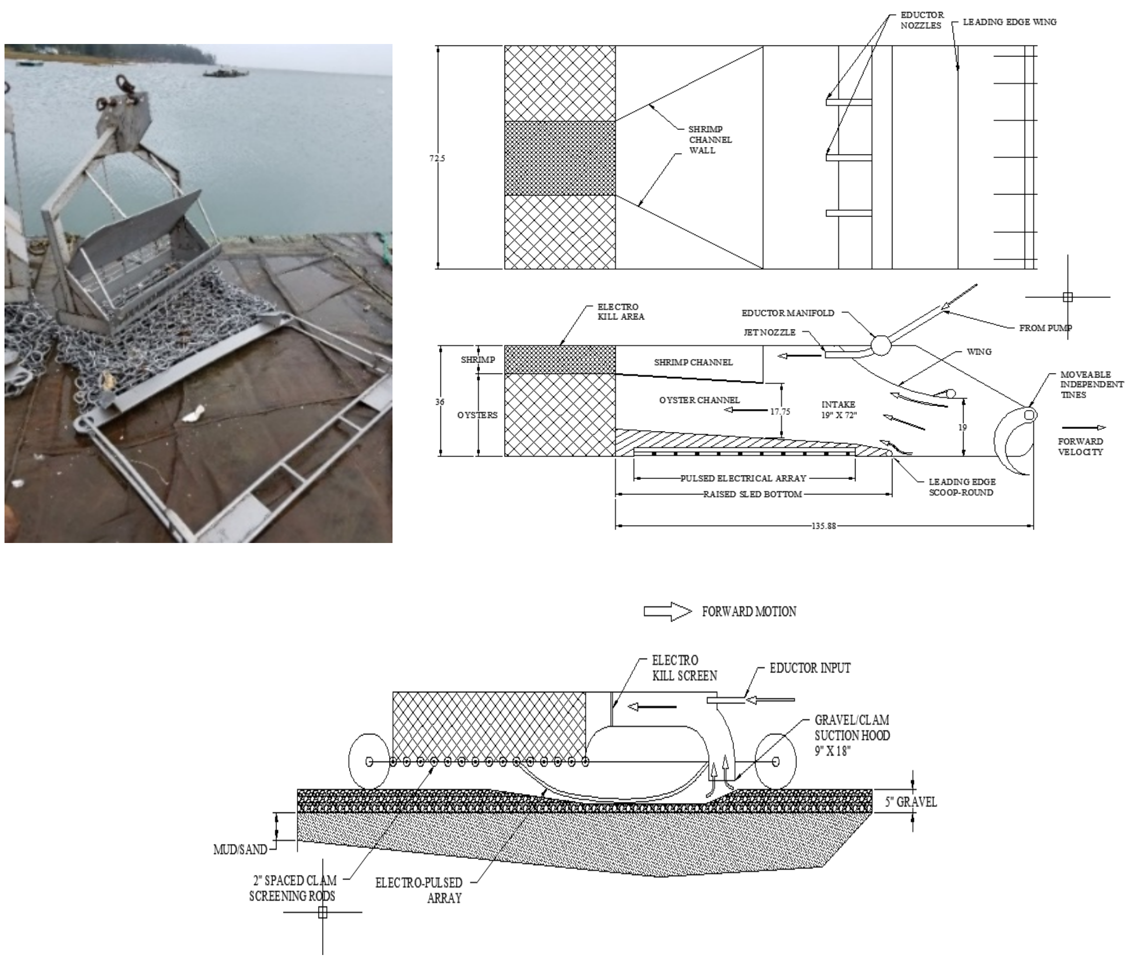

Figure 3 Traditional Willapa Bay oyster dredge and Griffin Team conceptual multi-tasking oyster harvester and clam harvester, incorporating "eductor" pump and electro-pulse technology

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.

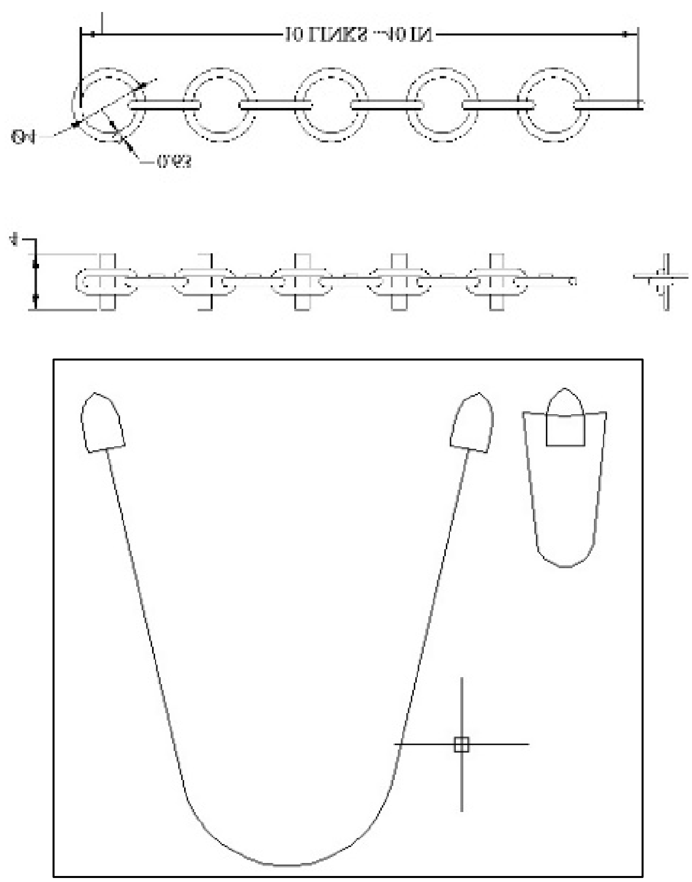

Figure 5 Chain examples and Griffin Team sketch of workboats towing long chain(s)

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.

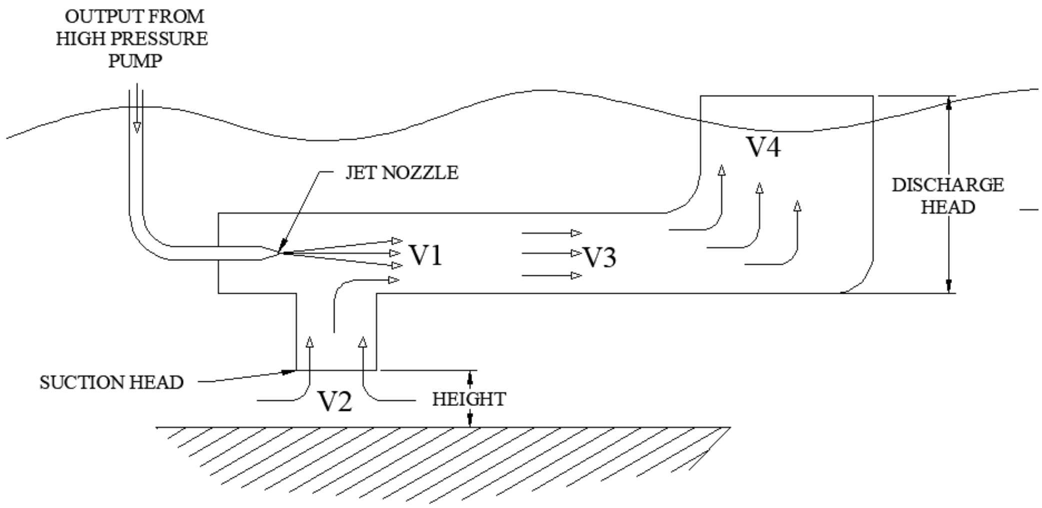

Figure 6 Physics of Eductors and model of multi-tasking Eductor sled

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

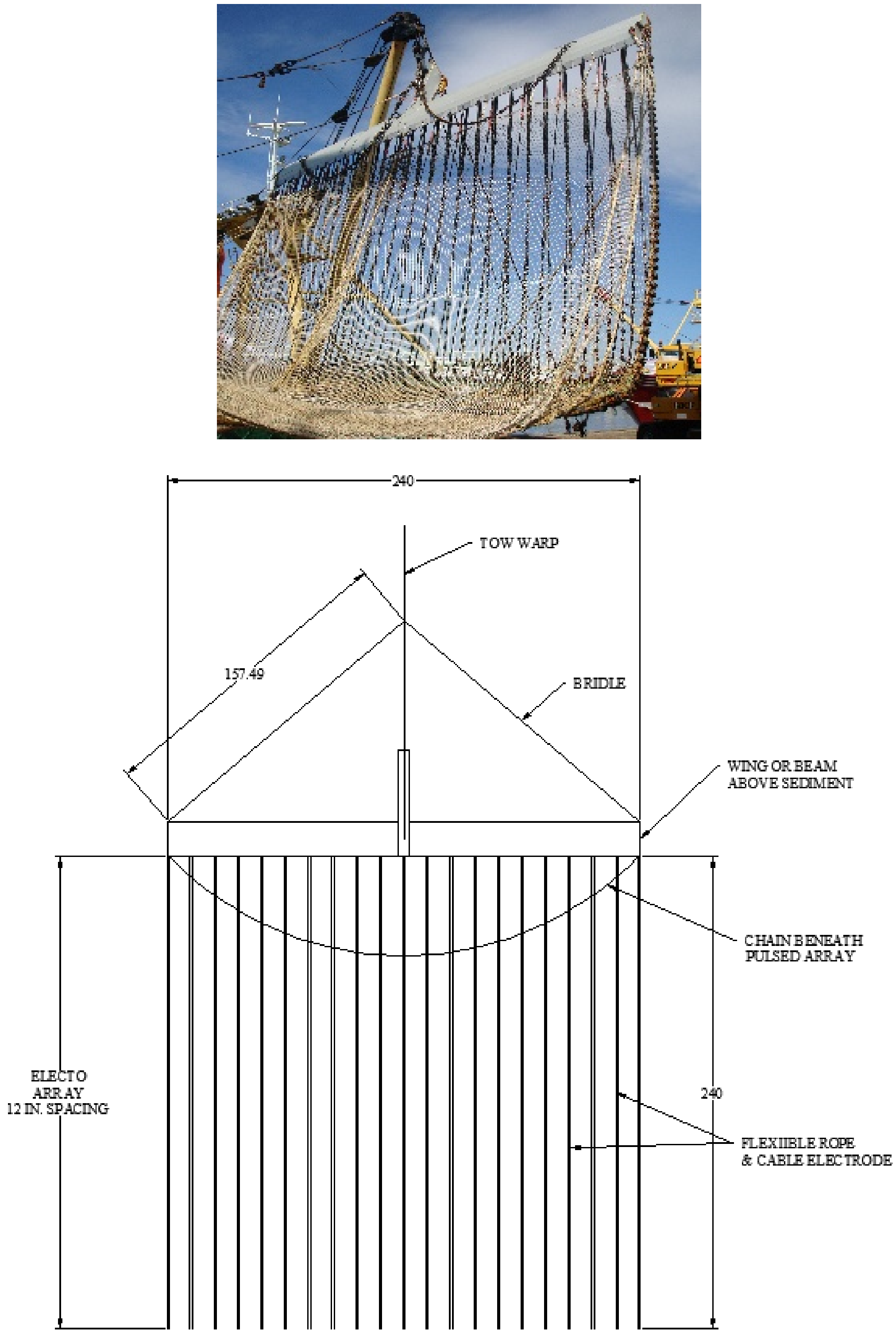

Figure 7 Dutch Pulsewing trawl and Griffin Team 20ft wide Willapa Bay Electro-Pulse concept

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.

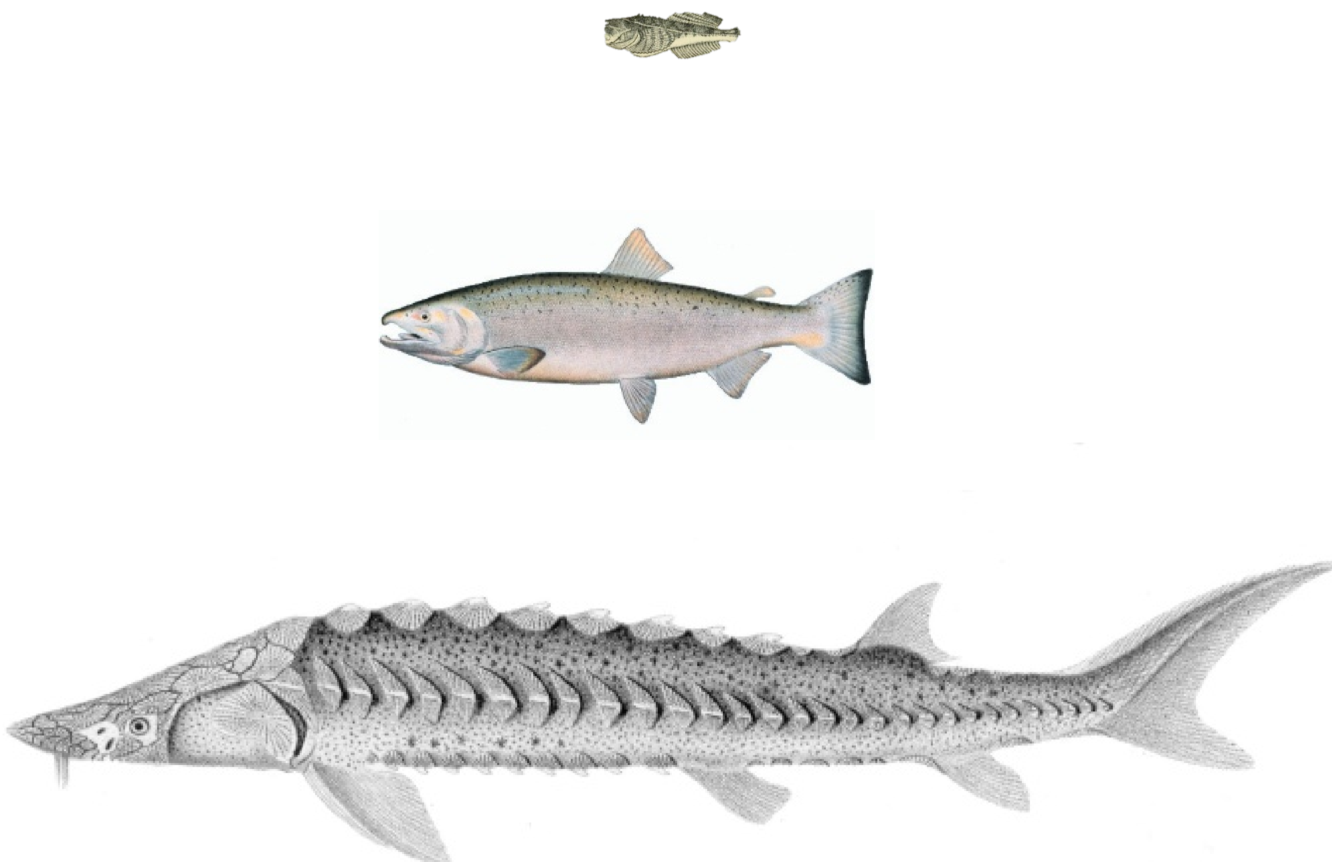

Figure 8 Burrowing ghost shrimp predators include Pacific staghorn sculpin, Pacific Coho Salmon, and Green Sturgeon

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.

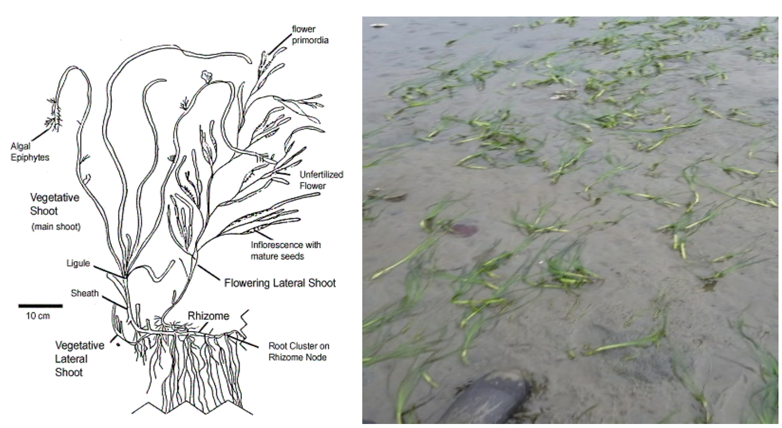

Figure 9 Eelgrass illustration (*Z.Marina*) and Willapa Bay eelgrass bed

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.

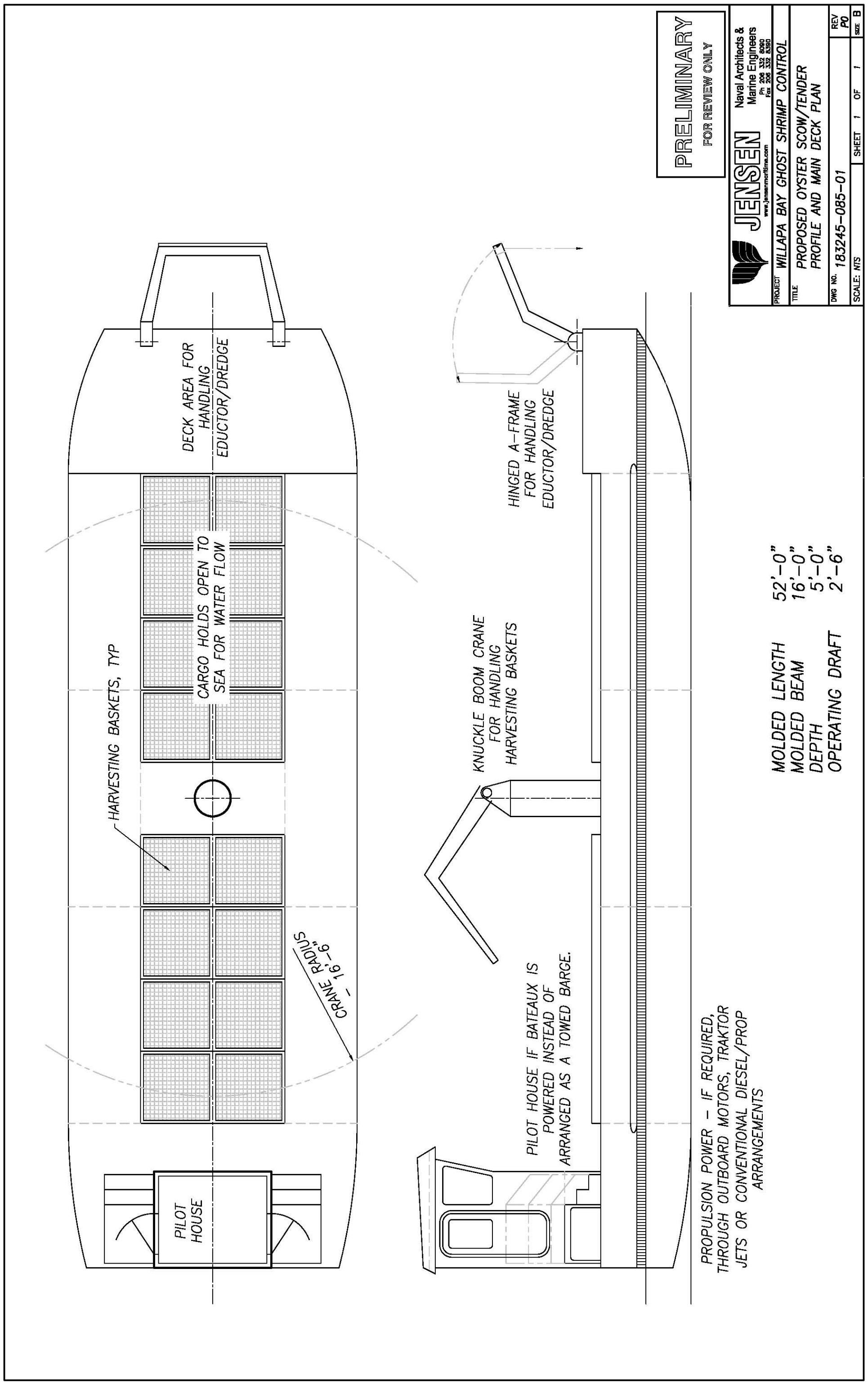

Figure 11 Griffin Team New Bateaux for Mobile Multi-tasking shellfish harvesters

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.

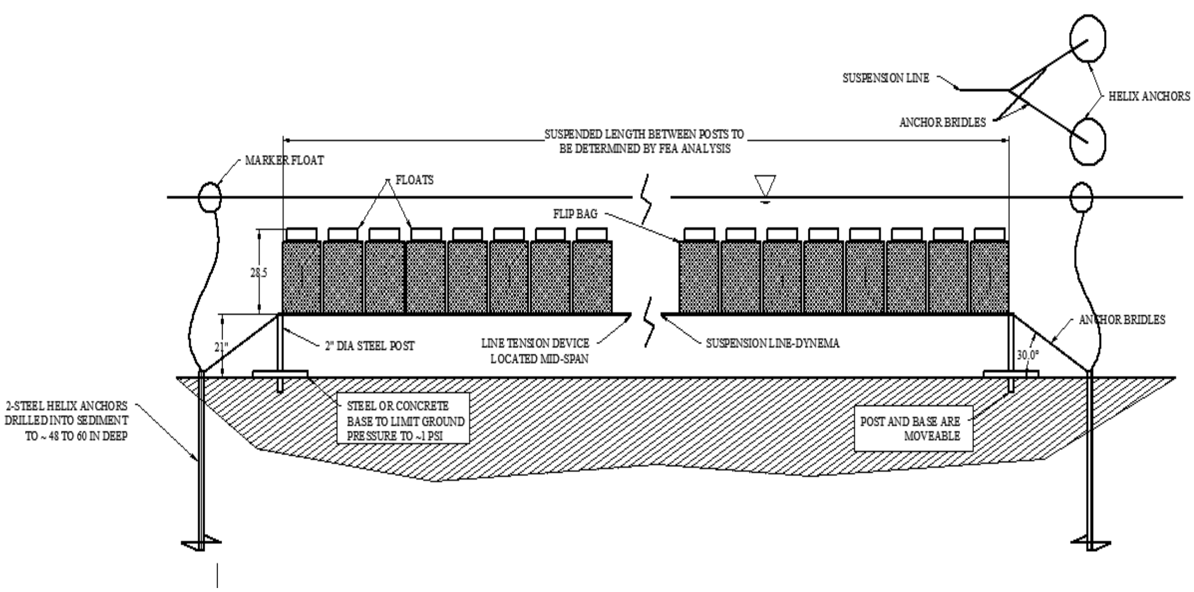

Figure 12 High tension flip bag system

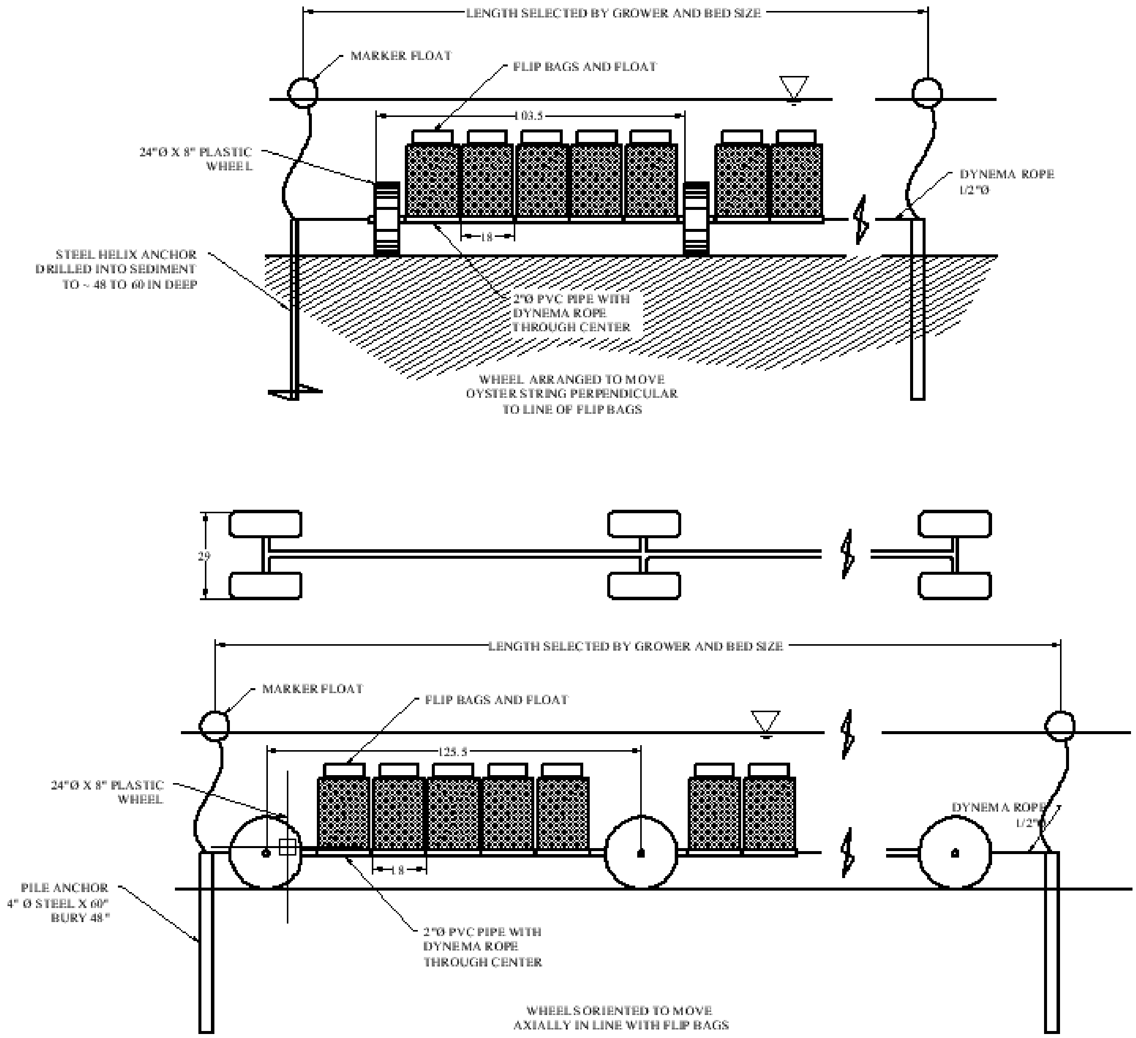

Figure 13 Use of wheels to support flip bag system

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.

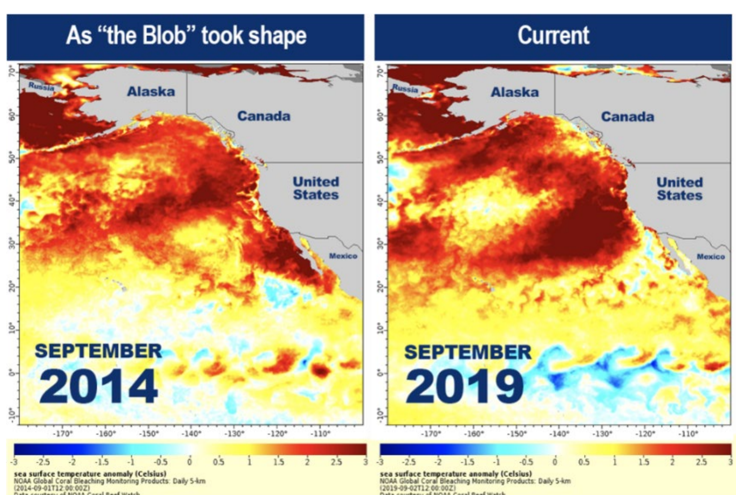

Figure 16 The current thermal Blob off the Washington coast https://www.forbes.com/sites/allenelizabeth/2019/09/05/another-warm-blob-is-forming-in-the-pacific-ocean/

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.

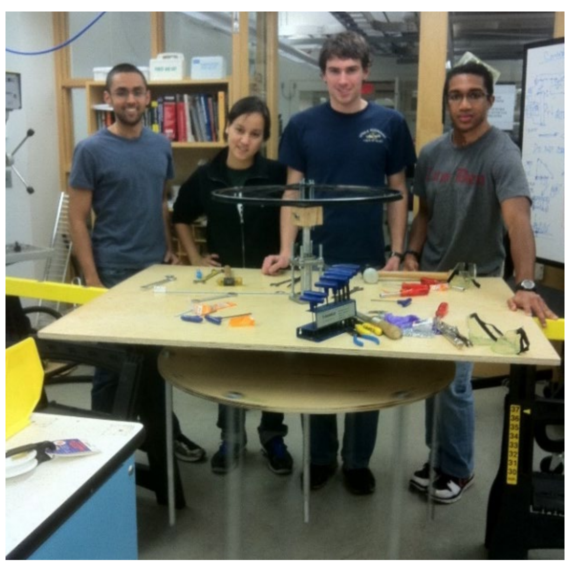

Figure 17 Low speed deep-ocean electric generator model in design incubator - 2011