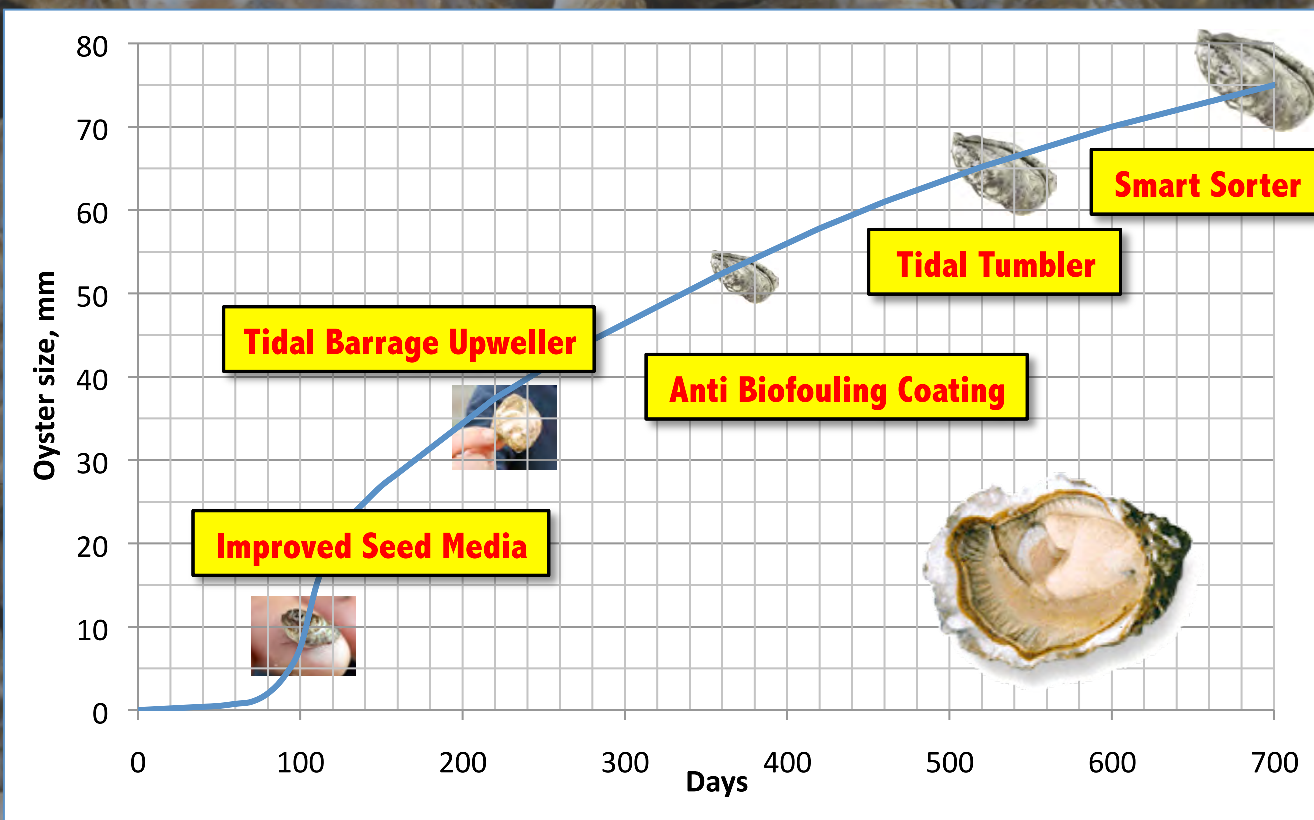
Oyster Aquaculture Engineering Technologies



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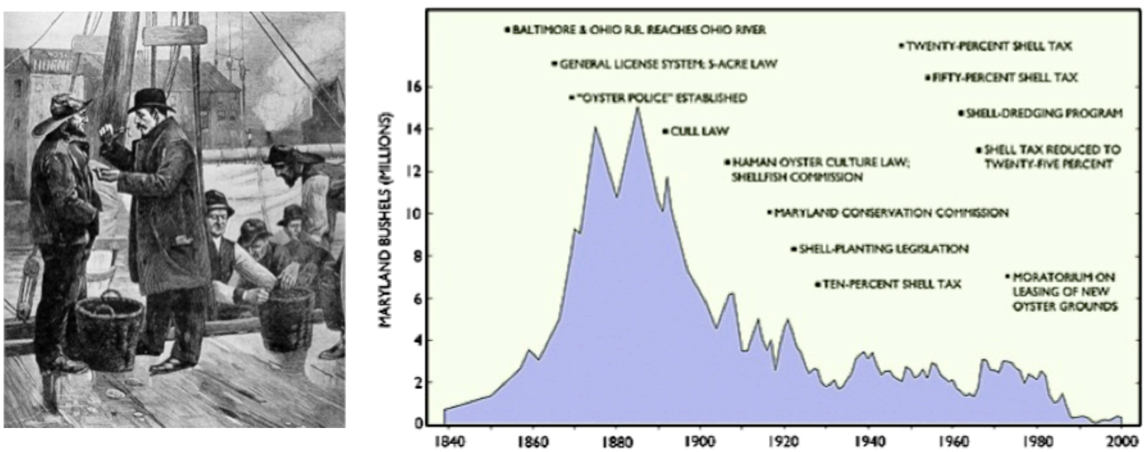
Executive Summary

This proposal is in response to the National Oceanic and Atmospheric Administration's Small Business Innovative Research program solicitation NOAA 2012-1, subtopic 8.2.3F, *Improving Environmental Sustainability and Competitiveness of U.S. Marine Aquaculture*. "The purpose of this subtopic is to develop innovative products and services to support the development of an environmentally, socially, and economically sustainable marine aquaculture industry in the U.S. in a way that is compatible with healthy marine ecosystems and other users of coastal and ocean resources." We are focusing on equipment for tidal water oyster aquaculture that will drastically reduce labor intensity and utilize renewable tidal energy.

According to Donald Webster, oysters have been an integral part of the life of the Chesapeake Bay as early 1612, when Captain John Smith remarked on the abundant oyster reefs. After the Civil War, seafood dealers in New England saw the rich oyster deposits in the Chesapeake and sent their technologically advanced vessels to harvest them, which precipitated the decline in harvests, as shown below.



A history of oyster harvest laws and harvests in Maryland [Webster, D., "Maryland's Oyster Fishery: Let's Enter the 21st Century," *Maryland Aquafarmer Online*, Fall, 2003]

Maryland has recently enacted laws to encourage oyster aquaculture and the goal of our proposed research is to improve the economic viability of sustainably farming oysters on the Chesapeake Bay. Five distinct technology innovations that follow the progression of oyster growth are proposed for the SBIR Phase I research:

1. Improved seed media – novel geometries and material systems that will allow oyster seedlings to grow faster with less energy use.
2. Tidal barrage upweller – an upweller that is powered by stored tidal water rather than high-velocity tidal currents.
3. Anti-biofouling surface treatment – non-toxic coating that can be applied to aquaculture equipment to minimize cleaning labor and improve oyster growth rates.
4. Tidal-powered tumbler – this novel growout gage will utilize the tidal change in water depth to clean oyster as they grow. It will also permit in-water sorting.
5. Smart sorters – a low-cost, portable computer vision oyster sorting system that can be brought to farms on an as-needed basis.

Equipment will be developed and tested with the following goals:

- Improve shellfish feeding rates
- Reduce labor required to bring oysters to market size
- Improve quality and consistency of delivered product
- Utilize renewable energy for active system components
- Reduce negative environmental impact of oyster aquaculture
- Develop equipment that can be manufactured domestically

Project Team

Eric Greene Associates, Inc.

Eric Greene Associates was founded in 1988 to develop composite material structures for the marine environment. Mr. Greene is a MIT-trained naval architect who has done work for the U.S. Navy, commercial and recreational ship owners, and serves as the materials subject matter expert on the international committee to develop design standards for ocean renewable energy devices. His company has completed six research projects for the Ship Structure Committee and Mr. Greene has also managed multi-million dollar R&D efforts for the U.S. Navy. Mr. Greene specializes in technology transfer among diverse industries as well as composite structures design and manufacturing training. He will serve as Principal Investigator for the Oyster Aquaculture Engineering Technology project and will draw upon his experience working in the same capacity on a DoD SBIR Phase II project.

University of Maryland Wye Research and Education Center

Mr. Donald Webster is the Senior Agent, Agriculture & Natural Resources, Marine Science at the University of Maryland's Wye Research and Education Center. His expertise is in marine science programs concentrating on aquaculture including commercial fish and shellfish production methods, pond management, and aquatic weed control; certification training for aquatic applicators; aquaculture policy. He currently is the Principal Investigator for Oyster Aquaculture Education & Training Project 2A, a three-year program to transition commercial watermen to shellfish aquaculture. He has been an advocate for oyster aquaculture in Maryland since the 1970s and will provide invaluable guidance on proposed research activities. He also works very closely with Maryland's community of waterman, which will help to accelerate commercialization of developed oyster aquaculture engineering technologies.

Chesapeake Fresh Oyster Company

Chesapeake Fresh is a relatively new Maryland oyster aquaculture venture that is full of enthusiasm and innovative ideas. The company is funded by a group of successful investors and by Maryland's shellfish aquaculture loan program. Their mission is to grow top-quality oysters throughout the Chesapeake Bay region, starting with their first farm on St. Jerome's Creek in St. Mary's County, Maryland. They are devoted to building a successful oyster business by investing in the latest technology and forming partnerships with experienced watermen and aquaculturists, research facilities, and environmental organizations so that they can develop efficient, sustainable farming practices that produce a quality product in a safe and healthy environment. They will serve as the primary commercialization outlet for developed technology.

Identification and Significance of the Problem or Opportunity

As recently as the 1970s, Maryland was able to sustainably produce 2.5 to 3 million bushels of oysters annually, which has been reduced to about 100,000 bushels a year since 2002. Figure 1 shows annual Maryland oyster harvest data since 1950. Maryland has recently recognized that aquaculture is the way to bring back this once thriving seafood industry. Improved equipment is required to make oyster aquaculture economically viable.

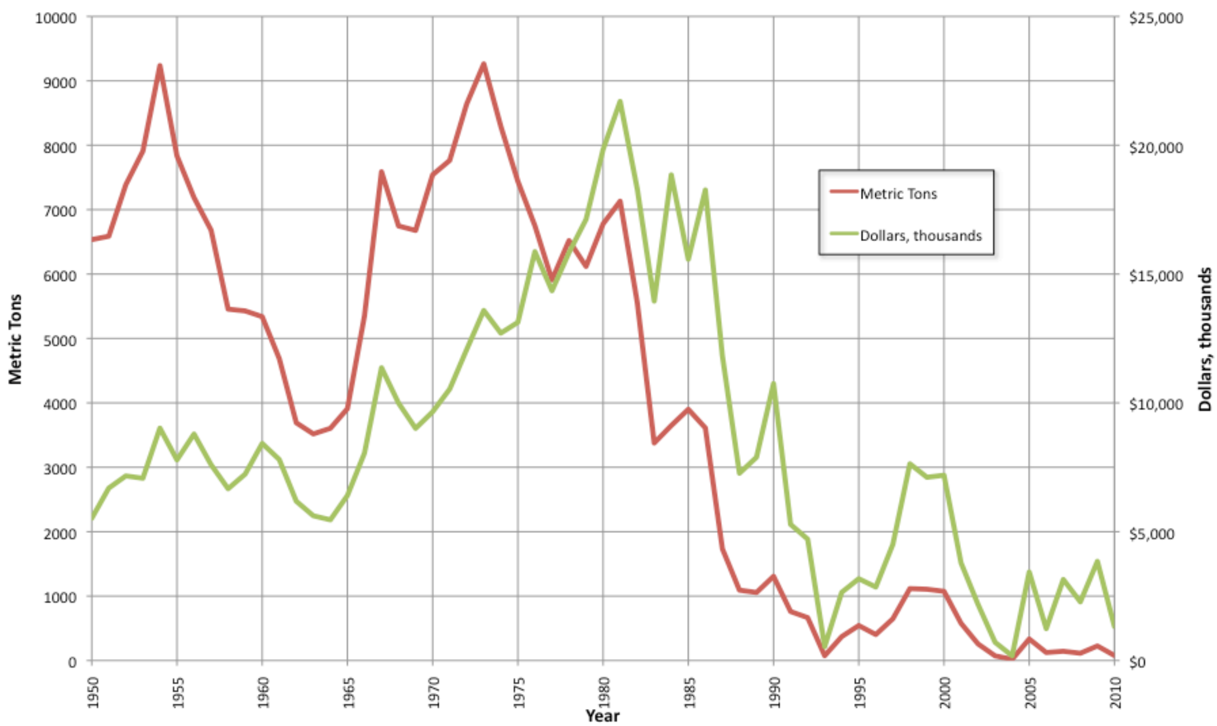


Figure 1. Maryland Eastern oyster harvest [from NOAA's State of the Coast, 2011]

Bivalve shellfish have unique characteristics that make them particularly well suited for aquaculture. Oysters are enclosed by a hard and relatively impenetrable shell that allows the use of a wide variety of culture methods. They filter fine food particles from the water and in their natural environment do not require added feeding or food supplements. Open water aquaculture of bivalve shellfish offers unique benefits, such as the potential for reduced costs; improved growth rates; and freshness associated with water quality. [Cheney 2010]

Tray culture of shellfish, particularly oysters, has been used for many years, with the trays either floating on the surface or fixed to wooden frames. It was discovered that the shellfish grew faster if the water flow was vertical passing through the oyster bed in devices called upwellers. Over the past thirty years there has been a steady development in the technology of upwellers, both in the US and Europe. They have become common in hatcheries, with water pumped upward through the bed of shellfish. [Riley 2001] Current upweller systems are very effective at feeding oyster seedlings but also require a lot of energy to operate and manual labor to maintain.

Maryland has historically relied on harvesting oysters off the bottom of public waters using traditional methods and equipment dating to the 1800s. The romantic vision of a Chesapeake waterman fighting the elements to harvest the Bay's bounty is now threatened by the severe decline of the oyster population, leading one researcher to call for a complete moratorium on harvesting. [Wilberg 2011] A lot of money and effort has been dedicated to restore natural "on-bottom" oyster populations and periodically the idea of privatizing Maryland's fishery was raised. "Almost every generation, a new commission or task force would form," according to Don Webster, a University of Maryland extension agent who has been trying to establish aquaculture in Maryland since the 1970s. "Almost all of them would come out with recommendations for leasing. And then it wouldn't happen." In 2009, the Maryland

General Assembly finally passed a law in that legalized leasing private beds to grow oysters. [Kobell 2011] This has created a tremendous opportunity to bring oyster harvest counts back to recent historic levels.

Maryland Governor Martin O'Malley's *Oyster Restoration and Aquaculture Development Plan* calls for: expanding aquaculture leasing opportunities; encouraging the development of aquaculture businesses; bringing back our native oyster; and creating new jobs and economic activity. [Roscher 2011]

One entrepreneur who is embracing the oyster aquaculture opportunity is Johnny Shockley, a third-generation waterman who has stopped crabbing to focus on oyster farming. He's built his upwellers and has customized a boat to hoist 200-kilogram growout cages from the bottom and mechanically sort the oysters by size. He said he has no regrets about leaving the traditional waterman's life to become an aquaculturist. He's hoping not merely to raise the bivalves for consumption, but to supply the equipment and eventually seed oysters to other oyster farmers. "We intend to grow an industry in the state of Maryland," he said. In addition, in the process, he added, "you're creating natural fish habitat, and you're cleaning the bay by adding millions of oysters to it." [Wheeler 2011]

Marinetics, currently the largest oyster aquaculture business in Maryland, claims they are a sustainable industry. "We put as many, if not more, oysters into the water as we take out. Our sustainably produced aquacultured product helps fill the consumer demand for oysters, thereby reducing the fishing pressure on the wild oyster population. We grow only oysters that are native to the Chesapeake Bay. There is no risk that we will introduce an invasive nonnative species into the Bay's delicate ecosystem." They also note that as oysters feed, they act as natural filters, removing massive amounts of micro-algae and silt from the water. A single oyster can filter up to 50 gallons of water per day. Marinetics has several million healthy oysters growing in the bay helping to filter the water. [Marinetics 2007]

Recent U.S. oyster aquaculture harvest data in Figure 2 shows the volatility of market value. Almost 97 percent of the oysters we consume are produced via aquaculture. Globally, oyster farming is a $3.1 billion industry that generates more than 4.6 million metric tons of oysters each year. [Brannen 2008]. Indeed, the main component of mollusk production in 2008 were oysters, at 31.8 percent. [FAO 2010]

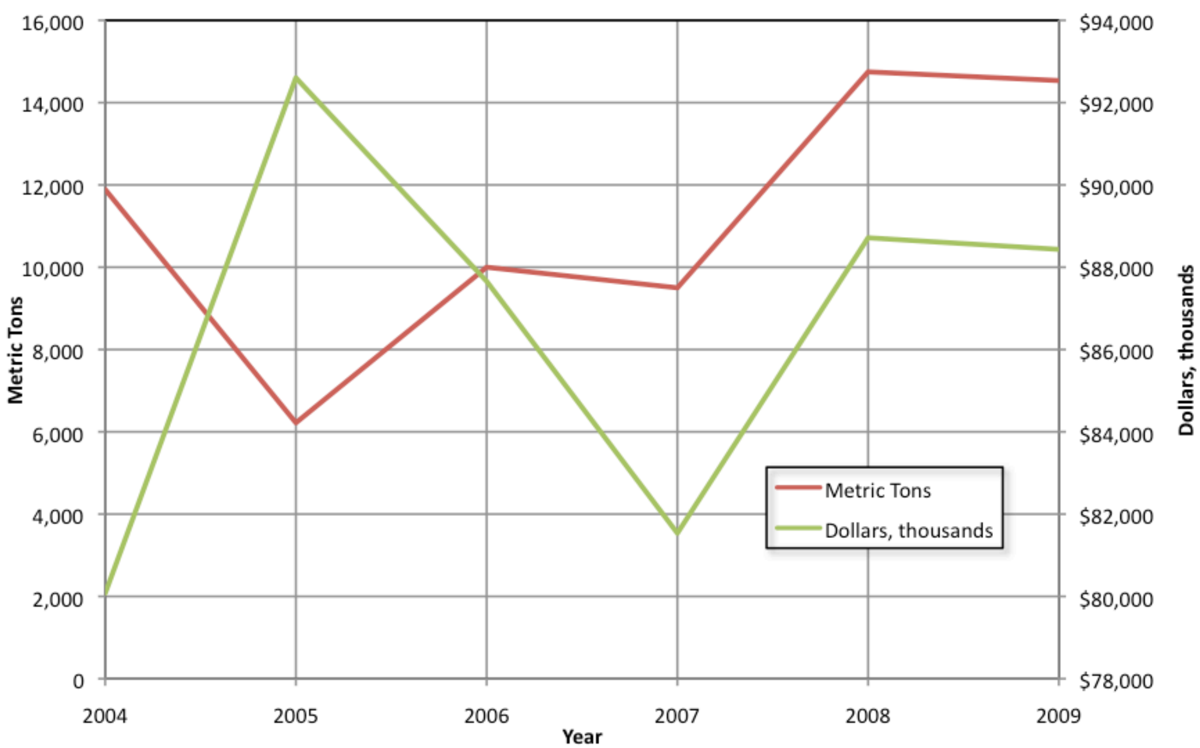


Figure 2. Estimated U.S. oyster aquaculture production, 2004-2009
[from Van Voorhees 2011]

In 2010, U.S. oyster landings yielded 28.1 million pounds valued at almost $117.6 million—a decrease of nearly 7.5 million pounds (21 percent) and $18.9 million (nearly 14 percent) compared with 2009. The Gulf region led in production (55%) followed by the Pacific Coast region (35%); and the South Atlantic region (5%). The average ex-vessel price per kilogram of meats was $9.22 in 2010, compared with $8.45 in 2009. [Van Voorhees 2011]

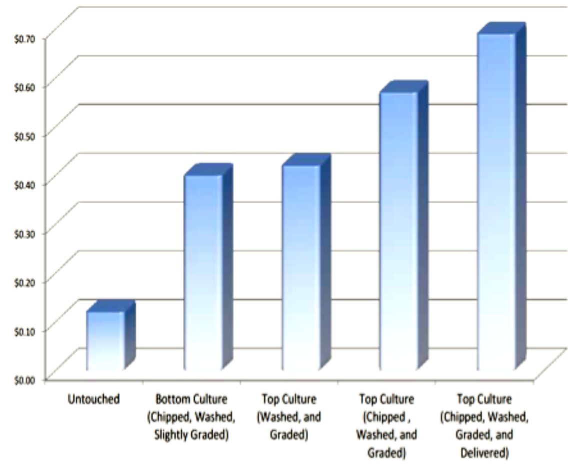


Figure 3. Oyster price per piece [Vilnit, 2011]

The annual per person consumption of oyster meat in the United States is around 40 grams, while France has the highest annual per capita oyster consumption in the world at over 1800 grams per person. Consumers perceive raw half-shell oysters based on characteristics including appearance (size, shape, color), odor, flavor (sweetness and saltiness) and texture (firmness). They prefer cup-shaped oysters where the meat fits the shell. [Lutz 2011]

Vilnit [2011] reported a large variation in the market value of oysters, as shown in Figure 3. Restaurants require oysters with uniform shape and size that don't require labor-intensive hand washing, as shown in Figure 4. Refined aquaculture technology will add value to oysters brought to market.

Figure 4. Hand washing oysters for the half-shell market [Vilnit, 2011]

Figure 5 shows that dramatically more aquaculture products are imported into the US than are exported. However, Figure 6 shows that that gap is narrowing for oysters. More efficient aquaculture equipment will accelerate this trend.

The Monterey Bay Aquarium's Seafood Watch® program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. They note that although oysters are cultured in 46 countries, the main areas of

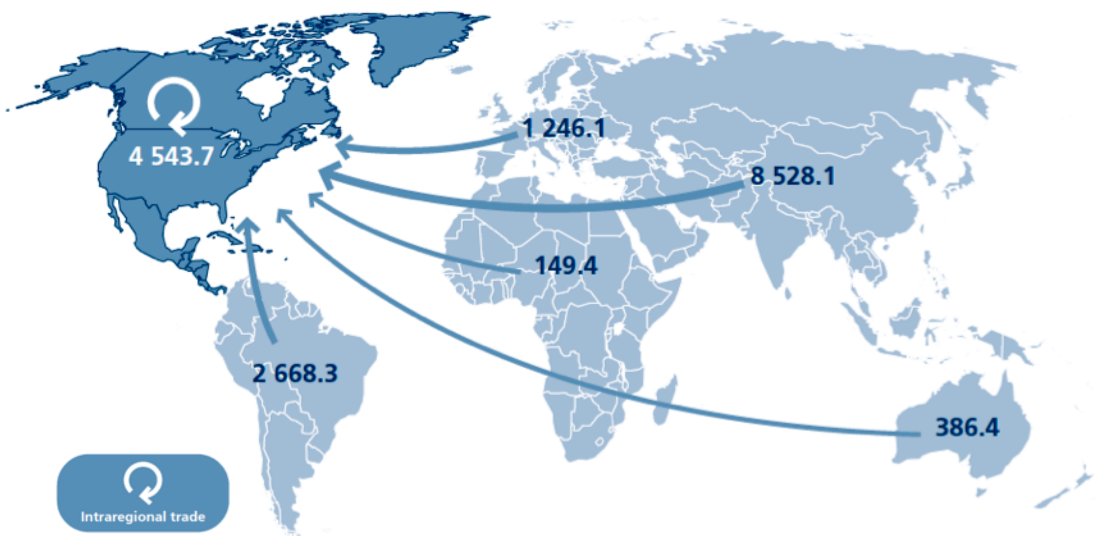


Figure 5. Aquaculture trade flows by continent (total imports in US$ millions, averages for 2006–08) [FAO 2010]

aquaculture production are China, Korea, Japan, the United States, and France. For oysters grown in suspended or off-bottom culture, only 'Risk of Escapes' and 'Risk of Disease Transfer' are considered of moderate conservation concern (whereas the other criteria are of low concern). This results in an overall recommendation of 'Best Choice' for oysters grown with this method of culture. [McNevin 2007]

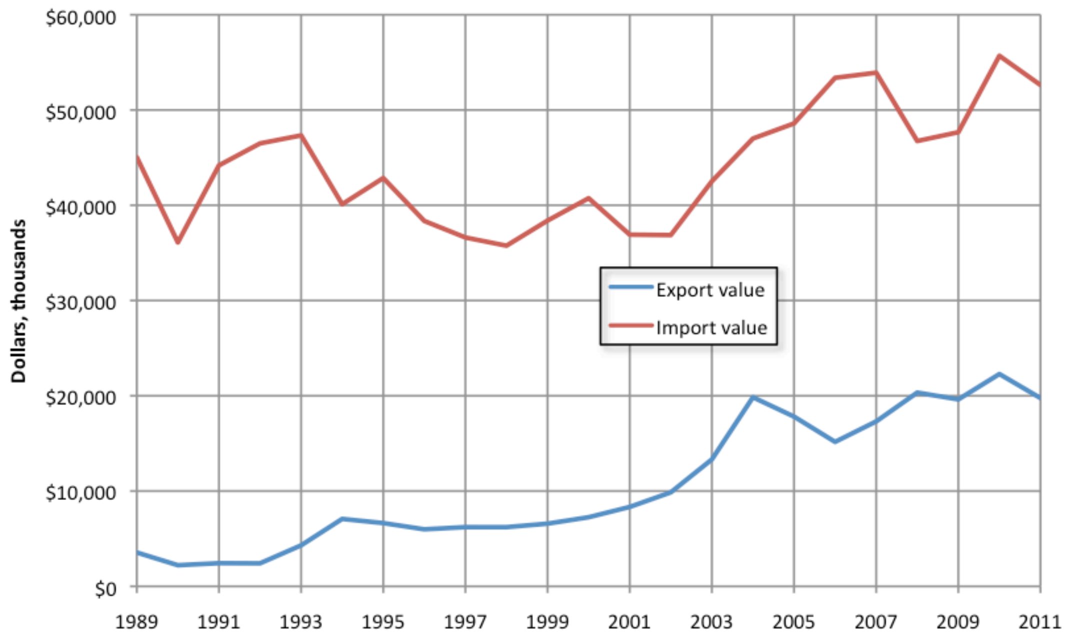


Figure 6. Value of oyster (fresh or prepared) imports and exports (data for 2011 is Jan – Sep) [Department of Commerce, Bureau of the Census, 11/14/2011]

At a 2007 aquaculture summit, it was observed that aquaculture is an emerging industry and research holds the key to its future success. Also noted was the need for developing and demonstrating improved techniques for shellfish and fish culture. [NOAA 2007]

In addition, a 2009 NOAA technical memorandum stated:

> The specific goals of research programs in environmental management for coastal shellfish aquaculture and cage culture include the *development and evaluation mechanized harvest methods* to increase management efficiency, *reduce labor costs, and minimize environmental impacts***.** Research is needed on technologies and management approaches to *control biofouling* in marine aquaculture, particularly for culture systems with direct exposure to the marine environment. Further *improvement of non-toxic and fouling-resistant materials and coatings is a critical need*. Available Small Business Innovation Research (SBIR) programs should also be promoted to the commercial aquaculture sector to encourage *proprietary research* or activities more suitable for private patents. The effectiveness of any transfer program will depend, in part, on *demonstration of technologies at an appropriate commercial scale* to encourage adoption. Technological innovation for shellfish aquaculture has the potential to *markedly increase U.S. shellfish production*, expand export opportunities, and improve understanding of the complex interrelationship between the natural and human environment in these production systems.
>
> *Off-bottom culture is a preferred method* in many areas of the world, and is common in the U.S. for mussel and oyster culture. For oysters, this method gives the grower *greater control over shell shape*, and sometime shell color. It also facilitates the production of a more *uniform or consistent product size* and can allow continuous product harvest. A primary advantage of controlled or containerized culture systems is that they improve the capability of growers to manipulate the production system and *improve the quality of their product during grow-out*. Until recently there has been little effort to identify *optimal configurations and construction features of shellfish grow-out systems*. The systems are typically configured to the maximum extent (or maximum permitted) of available and accessible water surface or bottom areas.

> Measurement needs for processing, packaging, and transport includes *non-contact instruments to determine and automatically sort shellfish* in the shell or meats by size or quality factors. [Browdy 2009]

The goals stated in the NOAA memorandum (our emphasis added) align with the technical objectives of our proposed research.

Phase I Technical Objectives
Research will focus on engineering technologies to develop oyster aquaculture nursery and grow-out equipment designed to increase sustainable production levels and improve the commercial viability of off-bottom oyster aquaculture. Equipment will be developed and tested with the following goals:

- Improve shellfish feeding rates
- Reduce labor required to bring oysters to market size
- Improve quality and consistency of delivered product
- Utilize renewable energy for active system components
- Reduce negative environmental impact of oyster aquaculture
- Develop equipment that can be manufactured domestically

Technology development will focus on equipment used to raise oysters from 2mm seed to market size with a specific emphasis on the techniques involved in the production of adolescent cultchless seed. Traditional equipment used for this stage of oyster growth includes upwellers, mesh bags, grow-out cages, floats and mechanical sorters.

The oyster aquaculture state-of-the-art is very labor intensive, which limits potential yields. While the demand for high-quality, half-shell oysters is on the rise, boutique growers are having problems meeting demand locally and for untapped domestic and overseas markets. Furthermore, growers currently participating in on-bottom or spat-on-shell aquaculture have difficulty entering into the cultchless aquaculture market due primarily to significant capital and labor constraints associated with seed rearing.

We expect that the equipment developed under this research will be mass-produced in the U.S., creating not only manufacturing jobs but also increasing the chances of success for oyster waterman transitioning to aquaculture methods.

Phase I Work Plan
Equipment development research will address the challenges of maximizing several variables of the nursery development phase: the amount of nutrients oysters receive during development; the speed at which sufficient open-water grow-out size is reached; and the consistency of the product in terms of shell shape, size and meat quality. Research will focus on reducing energy needs and labor intensity to enhance the economic viability of oyster aquaculture. Several novel solution paths that focus on materials and tidal energy are proposed.

In a report for the Northeastern Regional Aquaculture Center at the University of Maryland, Flimlin states:

> Off-bottom culture of oysters is typically better than placing bags directly on the bottom since sedimentation in the bags can reduce growth and potentially suffocate the growing oysters. Water column culture is common in the northern states, but ice damage and vessel traffic can present problems, as can the potential controversies between shoreline residents and commercial shellfish operations. All gear placed in saltwater for shellfish culture will become fouled with various kinds of organisms. Some of this fouling may just be a nuisance but the growth can be so extensive, it may restrict water flow or even smother the animals. Periodic cleaning of shellfish bags, cages, and predator control screens is essential to the survival of cultured shellfish. Upwellers are employed to raise juvenile clam seed from post set (~500 microns) to 10 to 12 mm before transfer to growout sites. Economic success in using land-based systems for growout has not been demonstrated, largely because of high-energy costs of pumping the water until the shellfish reach market size. [Flimlin 2008]

The goal of our proposed research is to reduce energy and labor costs associated with oyster aquaculture in order to improve the likelihood of economic success.

Aquaculture interests are a great mechanism for helping nudge the oyster population back up while providing very critical Chesapeake Bay filtering benefits. On the other hand, managing a fleet of "floating oyster beds" for public and environmental good should include avoiding negative impacts of beds-on-the-loose, as shown in Figure 7. [PAX River Online, 2010]

Figure 7. Oyster floats that the owner was unable to retrieve for many months [PAX River Online, 2010]

The Great Eastern Shellfish Company farm-raise their oysters in Chincoteague Bay south of Snow Hill, MD. They use the float method to grow shellfish that have received wide acclaim for their look and taste. They note that problems encountered in developing the business have included windstorms that have scattered their growout gear, causing them to spend time retrieving and repairing it. [Breza 2011]

Tidal-powered tumbler

There is opportunity to grow oyster aquaculture beyond the shores of the Chesapeake Bay. In Louisiana, Crockett's Grand Bay oysters are raised in baskets suspended several feet above the bottom in waist-deep water. Packed two hundred per basket, they are out of reach of the oyster drill, a predatory marine snail that has wreaked havoc on Mobile Bay's oyster reefs. They are also above the killing effects of the occasional plumes of low-oxygen water that sometimes move into area waters in the summer. [Raines 2011]

Our grow-out cages will be suspended just below the surface of the water to take advantage of optimal water column growing conditions while mitigating the adverse effects of surface waves. This will also make oyster aquaculture farms more acceptable to neighbors. A buoyant cage system will be held in place by tethers that feed through pulleys anchored on the seabed to floating marker buoys, as shown in Figure 8. As the buoys move with the tide, the cages are rotated. Wave energy will gently agitate the cages. This will reduce biofouling of the oysters and cage interiors. It will also increase nutrient exposure to the oyster and polish the shell for superior presentation.

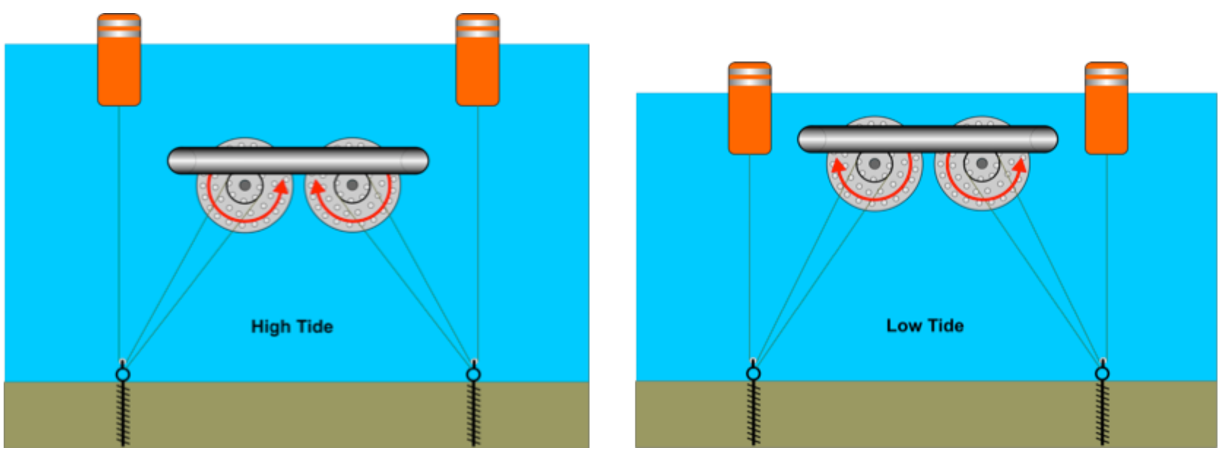


Figure 8. Tidal-powered oyster tumbler growout cage

In order for a mechanically operated growout cage to be economically viable, it will need to be larger than is currently size-limited by manual handling techniques used for oyster sorting and cleaning. These larger cages will be manufactured from composite materials so each one is not built on a one-off basis. Composite construction will also make a lighter assembly that won't corrode and can easily accept non-toxic surface treatments to combat biofouling.

The larger, cylindrical growout cage will facilitate in-water sorting of oysters by size. Figure 9 shows a schematic of how a sorter cage can extract smaller oysters using water pressure to transport them. The sorter cage will have openings larger than the growout cage, which will leave the faster growing oysters in the outer cage. The sorting process will be accelerated by rotating the cages as water is pumped radially inward. Phase I research will investigate cage materials and manufacturing technologies with a focus on developing domestic equipment manufacturing capability. A scale model of the tumbler growout cage will be built to validate the operational concept. A full-scale operational prototype will be constructed during Phase II.

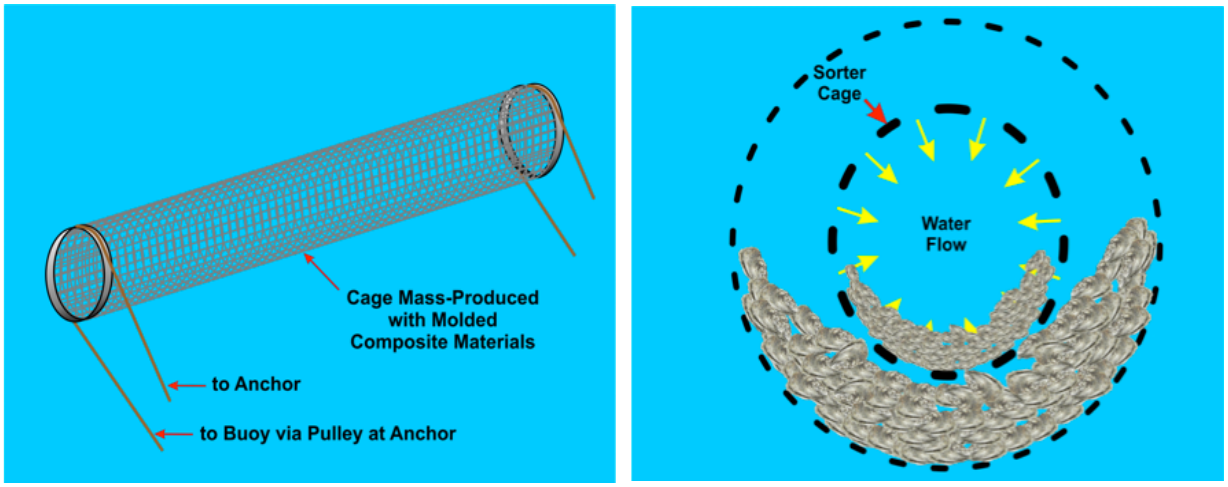


Figure 9. Composite growout cage (left) and method for in water sorting of oysters (right)

The main challenge growing and harvesting oysters is often described as a material handling issue. Full-grown oysters are very heavy, especially when we consider the water entrapped in the shell. Cages containing oysters often way hundreds of kilograms and require mechanized cranes. Sorting oysters in place can eliminate much of the labor and energy costs as the animals "weigh" much less in the water than on dry land.

Improved seed media

Upwellers consist of individual cylinders or boxes where oyster seed is placed. These containers are placed in a large tank or trough where water can be pumped through to feed the seed. The bottom of the containers are made of mesh that increases in size as the oyster seed grows. Routine maintenance of the upwellers is essential, particularly clearing the mesh of shellfish feces, pseudo-feces and silt that growing shellfish and bay water add to the system. If not kept clean, water flow will be impeded, thus limiting the amount of plankton the oyster seed has to feed on. [Flimlin 2007] Malinowski looked at the relationship between seed packing and the required screen size, as shown in Table 1. Our research will expand upon the data in Table 1 to consider alternate seed stacking geometries.

Presently, oyster seed is placed on very fine mesh to allow nutrient-rich water to flow during the nursery stage of development. Oysters are manually transferred to increasingly larger (and stronger) mesh materials as they grow. Upweller silos are typically square or round, as shown in Figure 10. Research will investigate the efficacy of novel media architectures, such as polyester spunbond, that can support oysters over a wider range of growth sizes and maximize effluent flow at each stage.

Table 1. Silo stocking densities for clams [from Malinowski 1986]

Sieve Mesh Size, mm	Approximate Clam Size Retained, mm	Number of Clams per ml	Optimal Stocking Volume, ml	Number of Clams in Optimal Stocking Volume (approx.)	Weekly Volume Increase (approx.)
Initial	0.75	2,500	125	312,000	100 - 300%
1.0	1.50	720	175	125,000	100 - 200%
1.4	2.50	116	300	35,000	100%
2.0	3.30	99	350	35,000	100%
2.8	3.90	45	600	27,000	90%
3.4	6.00	20	1,000	19,500	50%
5.7	8.30	6	1,500	9,000	35%

Candidate novel screen materials to be considered in our research include geotextiles used for landscaping retention and water filtering media. Figure 11 provides water permeability data for a specific variety of geotextile material. Polyester spunbond materials are also used as filter media and to assist vacuum infusion manufacturing methods used to build large composite parts. These materials are all very low cost and corrosion resistant, which opens up opportunities to spread oyster seeds over a larger area for improved feed rates. It also may prove to be more environmentally friendly to recycle this material rather than power washing to remove biofouling. Materials that show promise during initial screening will be coated with whatever biofouling treatment emerges from our research dedicated to that topic.

Phase I work will include a literature search to develop a database of candidate materials. Some of these materials are shown in Figure 12. Next, a simple test arrangement will be developed to measure how long it takes to fill a canister vertically via flow through a sample of the media in the bottom. Phase II research will measure actual oyster seed growth using materials that look promising during Phase I.

Figure 10. Square (left) and round (right) upweller silos [Leavitt 2010]

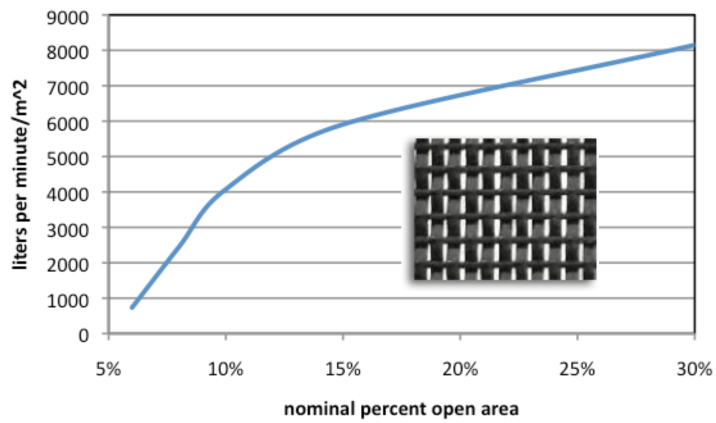


Figure 11. Water flow rates through geotextile materials [Carthage 2011]

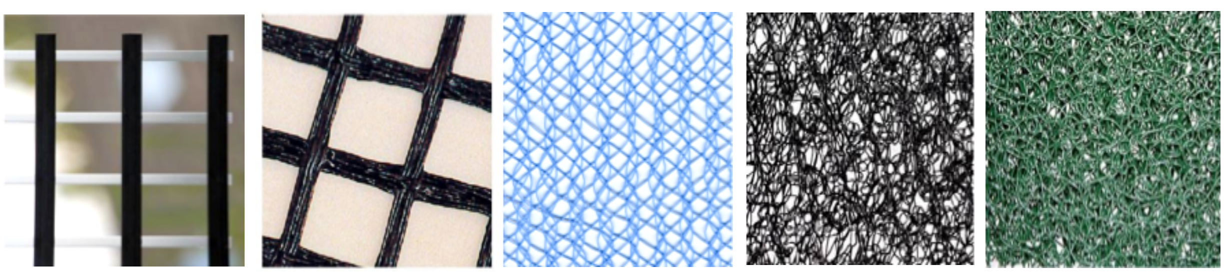


Figure 12. Geotextile materials with various open area geometries [Colbond 2011]

Tidal barrage upweller

Upweller systems currently utilize electric pumps with flow rates of approximately 300 liters/minute. This is very energy intensive and limits aquaculture activities to locations where a constant source of electricity is available. Tidal barrages capture a volume of water at high tide and release it at low tide, usually spinning turbines to create energy. This water storage principle will be investigated to determine if a sufficient flow rate can be developed to support an oyster upweller system.

Water flow in upwellers is typically generated by low head (axial flow), propeller pumps or electrically driven paddle wheels mounted in channels that receive the discharge from the upwelling containers. This causes a head difference between the level of the surrounding seawater and the lower water level in the discharge channel, with the result that water flows through the silos of the upwelling containers from the outside. Water then passes through the bed of contained spat and is discharged into a channel. The pumps or paddle wheels force water out of the channel back to the surrounding water.

According to Helm, a flow of between 10 and 20 liters per minute per kilogram of spat will carry a sufficient supply of food to the animals. Each spat holding container (assuming a 1 m^2 base area), of which there may be up to 32 in a unit, will hold up to 120 kilograms of seed at the maximum biomass loading, requiring a flow per container of 1200 liters per minute. The total flow per 32-container unit can therefore be in excess of 38,400 liters per minute.

A paddle wheel is more energy efficient in inducing a flow of this magnitude than is an axial flow, propeller pump. If power is not available at a remote site or on a barge floating in a tidal estuary then tidal power can be harnessed to operate an upwelling system. However, tidal-powered upwellers require current velocities of at least 50 to 100 cm per second (1 to 2 knots) to function efficiently. [Helm 2004] Many attractive oyster aquaculture sites have tidal ranges up to one meter but with current velocities less than 50 cm/sec.

The design for a tidal upweller in Maine was proposed by Mook in 1986 based on earlier work in Britain and on shore-based systems. The model was subsequently used in South Carolina [Baldwin 1995] before being modified for Georgia. The model's basic design consists of a floating tank structure with a wide scoop at the end, which directs incoming tidal water up into suspended bins that hold the seed mass secured on a screen, as shown in Figure 13. The water moves up through the seed mass, passes out into a collecting trough above, and exits at the rear of the unit. These systems are anchored in the river and turn with the tide, so the scoop always faces the tidal flow. [Power 2003]

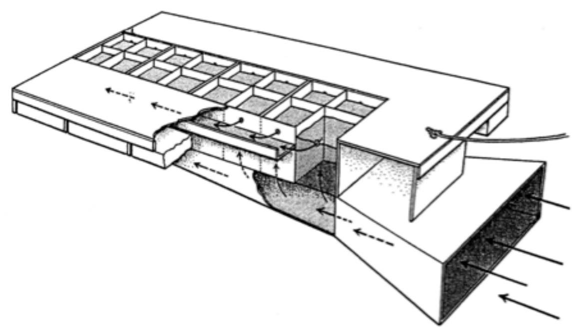


Figure 13. Three-dimensional schematic of the Tidal Powered Upwelling Nursery system [Baldwin 1995]

When designed in 1995, the Tidal-Powered upweller was estimated to have a projected annual operating saving of $3,220 to $3,460 over land-based nursery systems. [Baldwin, 1995]

The concept of "Ecological Aquaculture" encompasses design and monitoring of aquatic farming ecosystems that preserve and enhance the form and functions of the natural and social environments in which they are situated. Aquaculture is one of the planet's best choices for expanding new protein production but the real sustainability benefits of aquaculture's expansion will not occur unless alternative ecological approaches and ecological intensification of aquaculture are widely adopted. A compilation of various studies on energy use in aquaculture and animal production systems is shown in Figure 14. [Costa-Pierce 2010] Figure 14 illustrates that oyster

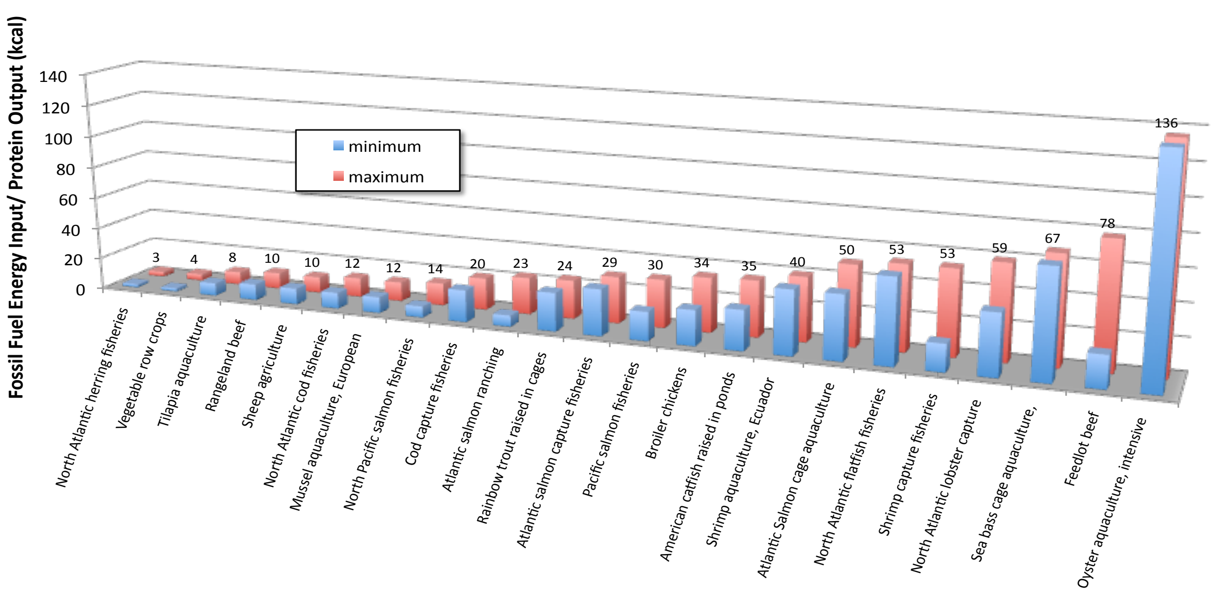


Figure 14. Ranking of fossil fuel protein production efficiencies for various aquatic and terrestrial food production systems [from Costa-Pierce 2010]

aquaculture presently requires the most energy per kcal of protein produced. A typical breakdown of this energy use is shown in Table 2 for a Pacific oyster farm. This illustrates the great incentive to investigate tidal energy for oyster aquaculture.

Table 2. Energy load of Pacific oyster farm [Mathies 2002]

Equipment	Rated Load	Hours used per week	Total Load per week
Purification System	400W	84	33.6 kWh
Holding Pond Aerator	2.2kW	7	15.4 kWh
Grader System	600W	15	9 kWh
Water Pumps	2kW	2	4 kWh
Power Washer	200W	2	0.4 kWh
Lighting	300W	15	4.5 kWh
Kettle	2.4kW		1.2 kWh
Fridge	100W		5 kWh
Microwave	800W		0.2 kWh
Computer Heater, etc.	300W	20	6 kWh
Total	**9.3kW**		**79.3kWh**

To increase the range where tidal energy can be used to power upwellers, our research will investigate the tidal barrage principle of storing a volume of water at high tide and releasing it at low tide. Mathies estimated the energy output of a micro hydro system situated on the inlet channel to a trout farm. With a head of 1.5 meters, a flow rate of $4m^3$/sec and assuming an efficiency rating of 80%, he calculated energy as:

$$(1.5 * 0.4 * 0.8) * 9.92 = 4.76kW$$

4.76 kW would be enough energy to supply aerators or a feeder system and would save this farm almost $4,000 per year, resulting in a payback period of just three years. Wave energy also offers real potential for coastal-based aquaculture facilities and Mathies recommends that the technological advances being made in this field should be keenly observed in the future. [Mathies 2002]

Water-powered “high lifter” pumps can pump larger volumes of water than hydraulic ram pumps. They can move volumes of up to $200m^3$/day (140 lpm) depending on the head. High lifters are also generally quieter in operation than hydraulic ram pumps. The high lifter uses head pressure instead of momentum in a downhill pipe. It uses a large volume of low-pressured water to pump a smaller volume of water at a higher pressure. A large piston acts with a smaller one to gain mechanical advantage. [Mathies 2002] This principle will be investigated during Phase I to determine if a tidal barrage on the Chesapeake Bay could power an oyster upweller.

Although the tidal range at the mouth of the Potomac River where Chesapeake Fresh Oysters are being raised is only 0.5 meters, Leavitt has shown that an optimized floating upweller requires only 100 continuous watts to operate. The following formula is used to predict the average power from a large-scale tidal barrage using conventional turbine generators for energy conversion:

$$P_{\text{ave}} = \frac{\rho g A h^2}{2T}$$

where T is the tidal period, taken as 12.5 hours. The equation predicts a required tidal barrage area of 3888 m^2. The proposed SBIR Phase I research will investigate direct utilization of our 0.5m tidal range to supply the required 50mm pump head using a barrage area at least an order of magnitude less than predicted by the above relation. Based on Leavitt’s data shown in Figure 15, a target flow rate of .08 liters/minute per cm^2 will be used.

Leavitt showed that the approximate number of clams in each silo given a target flow rate of 300 liters per minute for a 0.5 meter diameter silo and using a stacking density of 2000 shellfish/lpm-m^2 is about 120,000 shellfish @ 10mm each. [Leavitt 2010]

Leavitt also investigated the feasibility of a solar-powered floating upweller. Water flow and oyster growth rates compared favorably with conventional dockside systems. However, a ten-year return period assuming slip expense of $1000/year and $50/month existing electricity cost was required for the solar system to be economically favorable. [Leavitt 2010] It is optimistic to think that off-the-shelf solar electrical components could survive that long in a seawater environment.

Sun Farm Oysters of Block Island, RI recently received a grant from the U.S. Department of Agriculture to develop a paddlewheel upweller that relies on solar and wind power. [Sun Farm Oyster 2011] The owner of Sun Farm Oysters, Chris Warfel, has a background as a renewable energy engineer. We will contact him during our Phase I effort to determine if there is potential for project collaboration to leverage Government resources.

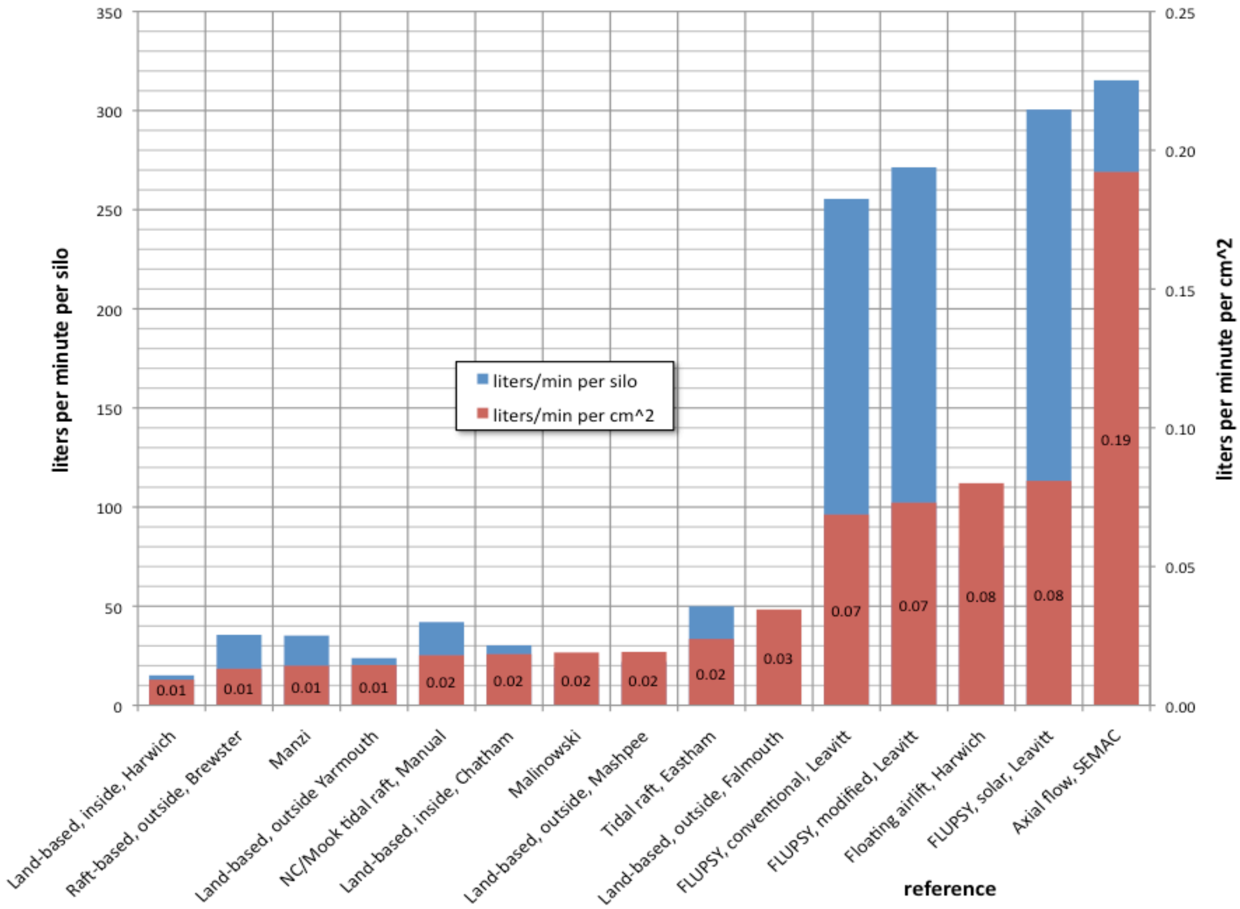


Figure 15. Upweller flow comparison data [from Leavitt 2010]

Equipment with antifouling and anticorrosion characteristics

Biofouling is a serious problem when it clogs the mesh of grow-out nets, bags, and cages, cutting off water circulation to the shellfish. This can inhibit growth and ultimately kill the shellfish unless measures are taken to control the biofouling. However, Maryland best management practices recommend not to use anti-fouling paints on shellfish culture gear. [Maryland Aquaculture Coordinating Council 2007] This creates an opportunity for the development of novel antifouling treatments for aquaculture equipment.

Figure 16. Silicon antifouling treatment on Norwegian surface effect ship [author photo]

Equipment developed under this research will be based on composite structural material that is corrosion resistant. Composites are also good receptors for various surface treatments. Hydrophobic, low surface energy coatings will be investigated to determine if these systems currently used for ships and in the wastewater treatment industry can work with aquaculture operations. Figure 16 shows this type of coating on a naval surface combatant.

Cleaning oyster cultures can equal 20% of market value and biofouling of equipment can reduce growth rates by over

40%. The cost to the European shellfish aquaculture industry is estimated to be between 130 and 260 million Euros per year. The biofouling of aquaculture equipment can accelerate the growth of marine organisms on shellfish. Mechanical cleaning of shellfish can involve drum washers or mechanized brushes, often as part of a processing chain before packaging for sale or transport. Shellfish cleaning needs to be repeated approximately every 8 weeks during the fouling season or just before selling. Person hours per annum spent on this technique can be up to 500 (5 to 40% of total person hours). Up to 20% of the stock can be lost. Tumbler drums used for oysters only break the edge of the shell, which is desirable and therefore not considered as damage. [CRAB 2007] The Tidal Tumbler developed under proposed research will help to minimize marine growth on the oysters themselves during growout.

Non-toxic antifouling coatings were evaluated with aquaculture equipment as part of research in Europe under the auspices of the Collective Research on Aquaculture Biofouling, or CRAB. Figure 17 shows some results of systems applied to netting. The results showed some improvement but were not optimal because the coating systems were not formulated specifically for the material to which they were applied.

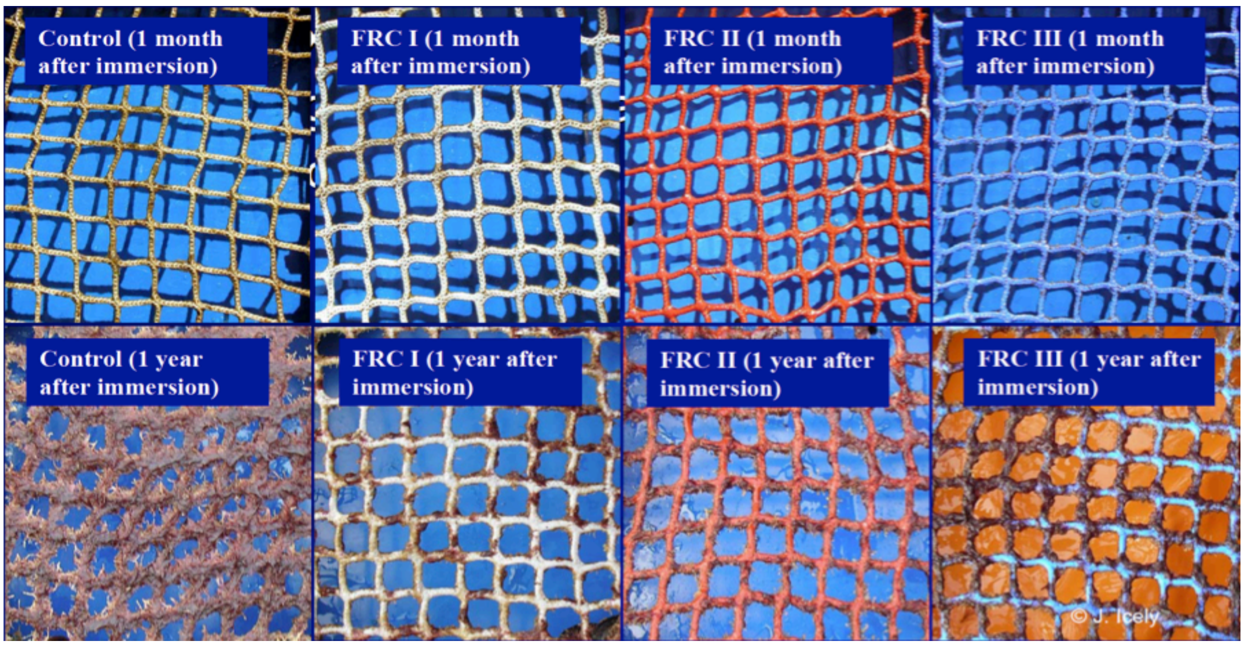


Figure 17. Evaluation of non-toxic antifouling coatings on aquaculture synthetic nets [CRAB 2007]

During Phase I we will evaluate several low surface energy antifouling treatments applied to composite material structural elements as per manufacturer's directions. In Phase II, actual grow-out equipment will be coated to evaluate the durability of these systems in service.

Smart sorters

Oysters are presently either sorted after manual inspection or by passing through mechanical sorters with various sized holes. The cost of video image processing systems has fallen a lot recently and is now used by high-volume processers for sorting oysters on a conveyor system.

Video imaging is often considered in conjunction with automated shucking concepts. The high pressure shucking process requires 100–800 MPa of hydrostatic pressure to destroy pathogenic organisms and separate the adductor muscle from the shell. The release of the adductor muscle from the shells is believed to be caused by the denaturation of the muscle proteins and connective tissues to give a gelatin transition, which results from the disruption of non-covalent interactions in the tertiary protein structures. The biggest drawback of this process is cost. High pressure processing vessels cost from $750,000 to $2,000,000. One of the most promising shucking technologies that has not been fully investigated is the use of lasers, which would allow the precise application of heat to the adductor muscle only. This was investigated by Fred Wheaton at the University of Maryland in conjunction with oyster positioning and imaging technologies. Figure 18 shows the general features of an oyster the must be recognized and quantified by a sorting system. [Martin 2006] Smart oyster sorting technology developed under the proposed research will consider future automated shucking technologies.

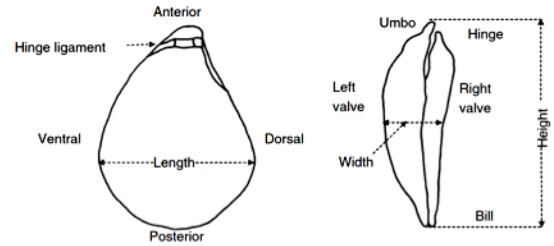


Figure 18. Diagram depicting anatomical features and the height, width and length of an oyster [Martin 2006]

The traditional method of human subjective evaluation in the food processing industry is being replaced by automated, camera/computer-based systems. These systems, known as machine vision (MV) or computer vision (CV) systems, have been successful in objective evaluation of various food products**.** Figure 19 shows image capture screens from some CV oyster sorting systems currently available. These systems work by capturing the image of an object, processing the image to measure the desired parameters, comparing these parameters with predefined inspection criteria, and then helping to make processing decisions. Wheaton and So worked to automate oyster hinge line detection using MV with a color camera. They determined circularity, rectangularity, aspect ratio, and Euclidian distance to recognize the hinge from other dark objects on the hinge-end of the oyster. Lee developed a 3-D oyster meat volume measurement method that truly measured the volume instead of estimating oyster volume from 2-D image. None of these existing systems measure oyster shape quality. To estimate the volume of oysters, a method based on cubic splines was developed. Fifty oysters each from Florida, Texas and Alaska regions were used to test the method that predicted volume and weight for oysters. Good correlations between predicted and measured volumes were found. [Gümüş 2011]

Figure 19. Computer vision oyster grading systems from Chesapeake Bay Oyster Co, VA (left) GP Graders, Australia (center) and Mulot, France (right) [video capture from company websites]

Current state-of-the-art CV oyster sorting systems are capital-intensive endeavors that are typically part of a large, factory-style conveyor system. Our research will focus on off-the-shelve CV systems developed for other industries that use low-cost digital imaging technology. We will also investigate the use of infrared imaging to determine if more information about oyster meat size and quality can be detected before shucking. Ultimately we would like to develop a trailer-based sorting system that could be transported to smaller growers on and as-needed basis, much as bottling factories in tractor-trailers travel to small wineries to minimize up front capital costs. Phase I will include a literature search and system vendor contact. We anticipate building a prototype system with Phase II funding.

Related Research or R&D

Mr. Greene is actively involved with the development of design standards for hydrokinetic renewable energy devices through his participation on the International Electrotechnical Commission. This exposes him to a worldwide range of ocean renewable energy devices. He also developed concepts for Micro Ocean Renewable Energy (MORE) to power sonobuoys for the U.S. Navy. His work on non-destructive evaluation methods has led to research and use of infrared imaging technology.

Mr. Donald Webster is the Senior Agent, Agriculture & Natural Resources, Marine Science at the University of Maryland’s Wye Research and Education Center. He currently is the Principal Investigator for Oyster Aquaculture

Education & Training Project 2A, a three-year program to transition commercial watermen to shellfish aquaculture. Mr. Webster has been an advocate for oyster aquaculture in Maryland since the 1970s and will provide invaluable guidance on proposed research activities. He also works very closely with Maryland's community of waterman, which will help to accelerate commercialization of developed oyster aquaculture engineering technologies.

Relationship with Future R&D

Over the past decade, spawning oysters at the Horn Point Lab Oyster Hatchery have resulted in the deployment of over one billion oyster spat to the waters of the Chesapeake Bay in the hopes of slowing the Chesapeake Bay oyster decline and restoring the health of the Bay. There is a major shortage of oyster shells for traditional spat on shell oyster reef restoration projects in the Bay and aquaculture oyster shells can serve as a valuable resource. The presence of oyster shells creates a hard bottom substrate that provides habitat for other bay organisms. The goal of our research is to dramatically increase the number of oysters in the Chesapeake Bay. This will impact the emerging field of systems ecology, which focuses on the interactions of aquatic species with each other and their physical environment.

Facilities and Equipment

By teaming with the University of Maryland for this effort, we will have access to the Aquaculture and Restoration Ecology Laboratory at the Horn Point Laboratory, which is a state-of-the-art building is the nation's first university research facility dedicated to restoration ecology. By integrating aquaculture-oriented approaches with ecosystem science, the laboratory helps produce effective and environmentally sustainable strategies to restore coastal environments such as Chesapeake Bay.

Supporting science for the sustainable development of living resources, the sophisticated equipment and instrumentation included in the new building supports cutting-edge research on water quality, biochemistry, geochemistry, marsh and submerged aquatic vegetation, nutrient cycling, and finfish and oyster aquaculture. Figure 20 shows some of the specialized oyster aquaculture equipment at the Horn Point Laboratory.

Figure 20. Broadstock conditioning tables (upper left); setting tanks (upper right); mass larval tanks (lower left) and conditioning system (lower right) at the 6000 m^2 Aquaculture and Restoration Ecology Laboratory at the Horn Point Laboratory [http://www.umces.edu/hpl]

Key Personnel and Bibliography of Related Work
Eric Greene, Principal Investigator

Education:
1979, S.B. in Naval Architecture and Marine Engineering, Massachusetts Institute of Technology

Professional Background:

1987-Present Eric Greene Associates, Inc., President. Mr. Greene founded Eric Greene Associates, Inc. to advance our understanding of composite materials for marine structures. Eric Greene Associates, Inc. clients range from the recreational megayacht industry to the military, allowing for technology transfer between diverse industries. Mr. Greene authored the highly acclaimed book MARINE COMPOSITES, which is available for download at the web site www.EricGreeneAssociates.com. He recently served as Principal Investigator for his sixth Ship Structure Committee project.

1990-2009 Structural Composites, Inc., Naval Projects Program Manager. Mr. Greene served as the Program Manager for the Composite Twisted Rudder project. In this capacity, Mr. Greene was responsible for securing $7 million in funding from various Government resources and managing all technical and programmatic aspects of the project.

1985-1987 Giannotti and Associates, Inc., Naval Architect. Mr. Greene's responsibilities with this firm started at the level of Project Engineer and graduated to Program Manager.

1982-1984 Consultant, Naval Architect. Mr. Greene provided engineering services for offshore racing sailboats of composite construction.

1981-1982 DLI Engineering Corporation, Marine Engineer. Mr. Greene was involved in test plan preparation, data acquisition and analysis of machinery condition monitoring.

1979-1980 Kiwi Boats, Inc., Naval Architect. Mr. Greene initiated the in-house engineering capabilities of this world-renowned producer of advanced offshore racing sailboats.

Selected Research:

International Electrotechnical Commission (IEC) TC 114, Marine Energy Devices, Materials Subject Matter Expert to Design Standards international committee.

Ship Structure Committee project on Marine Composites Non-Destructive Evaluation.

National Academy of Sciences committee member for Benchmarking the Technology and Application of Lightweighting for DoD Transportation Systems

Technology transfer assistance for major Norwegian shipbuilder supporting the U.S. Office of Naval Research (ONR)

Lecture series in the Netherlands on marine composite construction for the megayacht industry

Revision of NAVSEA Technical Publication T9074-AX-GIB-010/100, "Material Selection Requirements," to include updated guidelines for composites

Technology Road Map for Shipboard Naval Composites for ONR ManTech program

Selected Publications and Presentations:

Marine Composites NDE, Ship Structure Committee project SR 1464, 2011.

"Composites for Underwater Systems," presented at the SUBTECH Platform IPT Meeting, 2010.

"Composites for Marine Energy Systems," presented at the IEC TC 114 Design Requirements Meeting, 2009.

"Marina and Boatyard Indoor Rack Storage Sprinkler Protection," with D. J. O'Connor, G. T. Davis, and T. Gardner, The Fire Protection Research Foundation, Quincy, MA, Dec, 2008.

"Composites for Renewable Energy, 2008, http://change.gov/open_government/entry/composites_for_renewable_energy/

"U.S. Marine Composites…..think BIG," plenary session at the 4th International Conference on Advanced Engineered Wood and Hybrid Composites, Bar Harbor, ME, 2008.

"Built to Last: The Lifespan of Fiberglass Boats," Composites Manufacturing, Vol 22, No 10, Oct 2006.

Donald W. Webster, Subcontractor

Education:

2002 M.S., Agriculture and Extension Education, University of Maryland Eastern Shore
1974 B.S., Natural Resources, University of Rhode Island
1973 A.S., Marine Technology, University of Rhode Island

Professional Background:

2009-present Senior Agent, University of Maryland Extension, Wye Research and Education Center
1992-2009 Associate Agent, Cooperative Extension Service, Wye Research and Education Center
1985–1992 Associate Agent, Cooperative Extension Service, Easton MD
1974–1985 Associate Agent, Cooperative Extension Service, Horn Point Lab, Cambridge MD
1974-1976 Associate Agent, Cooperative Extension Service, Annapolis MD
1974 Biological Technician, National Marine Fisheries Services, Point Judith, RI

Professional Interests:

2010-13 Principal Investigator, Oyster Aquaculture Education & Training Project 2A to transition watermen to shellfish growers; extension education programs for commercial and restoration aquaculture; pond management; aquatic vegetation control; aquaculture policy; commercial fishing methods.

Selected Publications:

Webster, D. 2011. Education chapter in "Shellfish Aquaculture and the Environment." S. Shumway, editor, 17 chapters with international authors. Wiley-Blackwell Scientific Publications, Ames, IA.

Meritt, D and D. Webster. 2011. Classroom in the Hatchery. Invited chapter in "Advances in Aquaculture Hatchery Technology", G. Allen and G. Burnell, editors, 30 chapters with international authors. Woodhead Publishing Ltd., Cambridge UK. Publication date 2012.

Webster, D. 2010. Annual Report of the Maryland Aquaculture Coordinating Council. Principal author of report to the Governor and General Assembly with recommendations for advancing aquaculture. Maryland Department of Agriculture, Annapolis MD.

Webster, D. & D. Meritt. 2011. Remote Setting Systems. Training manual for Oyster Aquaculture Education & Training Project. Wye Research & Education Center. 12 pp.

Parker, M., D. Webster, D. Meritt & S. Dill. 2011. Economics of Remote Setting in Maryland. Instructional publication and accompanying spreadsheet for calculating costs in seed production. Maryland Sea Grant, College Park MD. 7 pp plus spreadsheet. On web at: http://www.mdsg.umd.edu/programs/extension/aquaculture/oysters/remote_setting/

Webster, D. 2009. Shellfish Aquaculture Development in Maryland and Virginia. Contracted report for bi-state industry needs assessment. National Oceanic and Atmospheric Administration. 51 pp.

Lazur, A., A. Hengst, E. Markin, D. Webster, K. Billing, D. Schuck and H. Buritsch. 2009. Community Pond Management. Maryland Sea Grant publication. 10 pp.

Webster, D, J. Buttner & G. Flimlin. (2008). Planning for Success in Your Aquaculture Business. Northeastern Regional Aquaculture Center publication No. 101-2008. 8 pp.

Memberships:

Maryland Aquaculture Coordinating Council, 2006-present (Chair 2006, 2008; Vice Chair 2007, 2011)

Maryland Oyster Advisory Commission, 2007-present

World Aquaculture Society, 1980-present; United States Aquaculture Society, Charter member

East Coast Shellfish Growers Association, 2006-present

Chesapeake Fresh Oyster Co.
209 Goodwood Gardens
Baltimore MD 21210
www.ChesapeakeFreshOysters.com

Eric Greene
Eric Greene Associates, Inc.
86 River Drive
Annapolis, MD 21403

January 13, 2012

Dear Eric,

Chesapeake Fresh Oyster Company ("CF") fully supports your SBIR proposal to research and develop critical improvements upon the equipment and systems currently implemented throughout the industry. We strongly believe, based on our experience in the field, that such improvements are necessary to accomplish our goal of expanding output by building partnerships with experienced watermen.

It is time to re-evaluate the oyster aquaculture industry's approach to culture and grow-out activities. The current "state-of-the-art" relies on equipment and processes that, while proven to be functional, are labor-intensive, uneconomical and inefficient in terms of material handling. We believe that your experience in composite material structures, renewable energy devices and non-toxic surface treatments makes you an ideal candidate for this research; one that can draw on established and applicable technologies outside of the industry.

In an industry that is already stymied by significant regulatory and environmental challenges, CF believes that it is our responsibility as an aspiring leader to work towards removing intrinsic barriers to entry such as the considerable amount of labor required in nursery culture. This grow-out phase currently relies on rudimentary upwelling systems that necessitate constant supervision and upkeep. These inefficient systems drive up the price of adolescent seed suitable for grow-out in relatively larger materials that are less susceptible to biofouling and therefore less labor-intensive.

In other words, the reason why CF so adamantly supports your SBIR proposal is not merely because we believe that improved seed media and grow-out materials will directly and swiftly increase our profit margins by reducing labor and improving growth rates and survival rates; we believe that the more significant benefit of your research will become apparent through commercialization of the new equipment and systems, which will allow CF to attract new partners by offering larger seed at lower cost and allowing watermen to concentrate on what they do best – growing *oysters*, not spat.

As such, we will provide you with 24/7 access to our 5-acre water-column lease (SM 736, 737, 738), our shellfish nursery (DNR Nursery Permit 2011-N-001), our confidential business materials, including financials and industry research, and we will remain dedicated to assisting and actively participating in the research and development process from its incipient stages through commercialization.

Sincerely,

Patrick Hudson
Managing Partner
Chesapeake Fresh Oyster Co.

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Solutions in your community

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124 Wye Narrows Drive, P.O. Box 169
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Cell: 410-310-7191
Email: dwebster@umd.edu

January 3, 2012

Mr. Eric Greene
Eric Greene Associates, Inc.
86 River Drive
Annapolis, MD 21403

Dear Eric:

I support your SBIR proposal on "Oyster Aquaculture Engineering Technologies" to develop enhanced culture equipment for shellfish aquaculture. An industry survey conducted during 2011 by the East Coast Shellfish Growers Association ranked this type of research among the highest priority issues. As you and I have discussed, material handling remains a significant challenge to developing successful shellfish culture businesses and lowering labor inputs will greatly aid in supporting profitable operations.

I am looking forward to participating in this project and believe that its success would find ready application along the coast. The project includes several areas of investigation that will need to intersect. The application of non-toxic antifouling coatings will be needed to support equipment such as the tidal tumbler and tidal barrage upweller in order to minimize the labor normally required to keep equipment in the aquatic environment free of organisms that will ultimately colonize and clog meshes. This restricts water flow and results in extended culture times which results in prolonged cash flow and, often, lower profits.

This project is the first that combines novel approaches to several problem areas in off-bottom culture systems and, as such, should ultimately lead to wide application in the shellfish industry. While the traditional method of culturing oysters in the Chesapeake Bay region was bottom culture, the depletion of that resource has led to an eighty percent decrease in the number of Maryland processing plants over the past three decades. The loss of processing capacity has led to a scarcity of the shell resource needed to properly stabilize bottom and caused growers to look for other innovative methods to culture their animals. Growing shellfish off bottom has advantages such as generally noted accelerated growth rates. Combined with contemporary genetic improvement in oyster lines through breeding and advanced hatchery production, this new technology could provide a very profitable method of raising shellfish.

E. Greene
03 Jan 12
Page 2

As an extension specialist with over thirty-seven years of experience I would certainly be pleased to participate in the development of this equipment and provide educational material and programs to ensure that the results are widely disseminated. The Oyster Aquaculture Education & Training Project that I am currently managing has several facets that would merge with efforts through the SBIR project to provide the seed needed to culture in the systems. We are also continuing to build strong ties with those in the industry through local educational programs designed to transfer the best available technology to our existing growers and the watermen who have decided to transition to aquaculture. The State of Maryland has emphasized the development of private cultivation as key to rebuilding the once important oyster industry. In addition to our training program funds have been made available through state agencies for watermen to obtain low interest, non-collateralized loans for the purchase of certain equipment, seed and shell.

While the history of the Maryland oyster industry was one that discouraged private aquaculture, the virtual collapse of it has shown that we must bring technology to its rebuilding. The components of this project combine to create advances on several fronts and we may well see them applied singularly or in a multi-tiered operation for the production of high quality oysters.

I look forward to consulting with you on this project should it be successful in obtaining SBIR funding.

Sincerely,

Donald Webster
Senior Agent
University of Maryland Extension

Consultants and Subcontracts
Donald W. Webster of the University of Maryland Extension Wye Research and Education Center, Wye Mills, Maryland.

Potential Commercial Applications and Follow-on Funding Commitment
Eric Greene Associates was contacted in the fall of 2011 by the Chesapeake Fresh Oyster Company to develop oyster aquaculture equipment. Chesapeake Fresh Oyster Company is an ambitious, young oyster aquaculture enterprise that has received funding support from the state of Maryland and currently has over one million oysters in the water. Currently, their objective is to produce a sustainable, high-volume harvest of consistently shaped, aesthetically pleasing oysters in the least amount of time, at the lowest cost possible and with utmost regard for the health of the animal and the surrounding environment. Their long-term goal is to lead a co-op of Chesapeake Bay oyster farmers with the mission of re-establishing a premium Chesapeake brand for farm-raised oysters in both local, national and international markets. When it became apparent that transformational oyster aquaculture equipment was required to improve economic viability, Eric Greene Associates choose to pursue this funding vehicle with the

understanding of close cooperation with the Chesapeake Fresh Oyster Company and a commitment to implement developed technology.

In partnership with the Chesapeake Fresh Oyster Company, Mr. Greene is pursuing a water column oyster aquaculture lease in the Shaw Bay region of the Wye River. Mr. Greene is part owner of property on Shaw Bay and this protected body of water will be an ideal location for commercial-scale validation of socially acceptable oyster aquaculture equipment. It is also only a few kilometers from the University of Maryland Extension's Wye Research and Education Center.

Cooperative Research and Development Agreements (CRADA)
The applicant is not currently a CRADA partner with NOAA or any other Federal agency.

Guest Researcher
The applicant is not a guest researcher at NOAA.

Cost Sharing
Cost sharing is not proposed for Phase I of this SBIR effort.

Equivalent Proposal or Awards
none

Prior SBIR Phase II Awards
none

References
Baldwin, Robert B., Monk, William, Hadley, Nancy H., Rhodes, Raymond J., and DeVoe, M. Richard, "Construction and Operations Manual for a Tidal-Powered Upwelling Nursery System," National Coastal Resources Research and Development, 1995.

Brannen, Colin, "Farmed Oysters," WWF Aquaculture Program, Washington, DC, http://www.worldwildlife.org/what/globalmarkets/aquaculture/WWFBinaryitem9682.pdf, 2008.

Breza, Luke, Producer's Panel, 2011Maryland Shellfish Aquaculture Conference, Doubletree Hotel, Annapolis, Maryland, Nov 15, 2011.

Browdy, C.L. and J.A. Hargreaves (editors). 2009. Overcoming Technical Barriers to the Sustainable Development of Competitive Marine Aquaculture in the United States. U.S. Department of Commerce, Silver Spring, MD USA. NOAA Technical Memo NMFS F/SPO- 100. 114pp.

Barry A. Costa-Pierce, Barry A., "Sustainable Ecological Aquaculture Systems:

The Need for a New Social Contract for Aquaculture Development," *Marine Technology Society Journal*, Volume 44 Number 3, May/June 2010.

Cheney, Daniel, Langan, Richard, Heasman, Kevin, Friedman, Bernard and Davis, Jonathan, "Shellfish Culture in the Open Ocean: Lessons Learned for Offshore Expansion," *Marine Technology Society Journal*, Volume 44 Number 3, May/June 2010.

CRAB – Collective Research on Aquaculture Biofouling, "European Best Practice in Aquaculture Biofouling," Commission of the European communities contract COLL-CT-2003-500536, 2007.

FAO Fisheries and Aquaculture Department, "The State of World Fisheries and Aquaculture 2010," Food and Agriculture Organization of the United Nations, Rome, 2010.

Flimlin, Gef, "Nursery and Growout Methods for Aquaculture Shellfish," Rutgers Cooperative Extension, NRAC Publication No 00-002, 2007.

Flimlin, Gef, Buttner, Joe and Webster, Don, "Aquaculture Systems for the Northeast," University of Maryland Northeastern Regional Aquaculture Center, NRAC Publication No. 104-2008

Gümüş, Bahar, Balaban, Murat Ö., and Ünlüsayın, Mustafa, "Machine Vision Applications to Aquatic Foods: A Review," *Turkish Journal of Fisheries and Aquatic Sciences*, 11: 171-181, 2011.

Helm, Michael M. and Bourne, Neil, "Hatchery culture of bivalves," FAO Fisheries Department, Food and Agriculture Organization of the United Nations, Rome, 2004.

Kobell, Rona, "Privatizing the Chesapeake," *Chesapeake Bay Journal*, .http://reason.com/archives/2011/10/25/privatizing-the-chesapeake/print, November, 2011.

Leavitt, Dale, "Shellfish Upweller Nurseries," Roger Williams University, WHOI Sea Grant, 2010.

Lutz, C. Greg, Sambidi, Pramod and Harrison, R. Wes, "Oyster Profile," Louisiana State University Agricultural Center, http://www.agmrc.org/commodities__products/aquaculture/oyster_profile.cfm, 2011.

Malinowski, Steve, "Small Scale Farming of the Hard Clam On Long Island, New York," prepared for New York State Urban Development Corporation, New York, New York, 1986.

Martin, Daniel E. and Hall, Steven G., "Oyster shucking technologies: past and present," *International Journal of Food Science and Technology*, 41, 223–232, 2006.

Marinetics, "Sustainable Aquaculture at Marinetics," The Choptank Oyster Company, http://www.marineticsinc.com/aquaculture.htm, 2007.

Maryland Aquaculture Coordinating Council, "Best Management Practices – a Manual for Maryland Aquaculture," http://www.marylandseafood.org/pdf/best_management_practices_manual.pdf, July, 2007.

Mathies, Mo, "The Potential for Renewable Energy Usage in Aquaculture," Damien Toner, Resource Development Section, Aquaculture Initiative, December 2002.

McNevin, Aaron A., "Seafood Watch Farmed Oysters Report," Monterey Bay Aquarium, February 2007.

NOAA's State of the Coast, http://stateofthecoast.noaa.gov/com_fishing/welcome.html, 2011.

NOAA, Summary of the National Marine Aquaculture Summit, http://aquaculture.noaa.gov, 2007.

PAX River Online: A "Save the Bay" Conflict - Aquaculture Flotsam, http://paxriveronline.blogspot.com/2010/09/save-bay-conflict-aquaculture-flotsam.html, 2010.

Power, A., Shierling, Thomas, Recicar, Todd, Lambrix, Joe, Eller, Nelson and Walker, Randel, "Tidal Powered Upwelling Nursery Systems for Clam Aquaculture in Georgia," UGA Marine Extension Service, Shellfish Research Lab, Marine Extension Bulletin 28, November 2003.

Raines, Ben, "Growing a pearl of an oyster in Grand Bay," *Alabama Press-Register*, November 27, 2011.

Riley, John, "Optimization of Tidal Upweller Design," Maine Aquaculture Innovation Center, MAIC Project # 99-12, September 2001.

Roscher, Karl R., Assistant Director, Fisheries Service, Maryland Department of Natural Resources, 2011Maryland Shellfish Aquaculture Conference, Doubletree Hotel, Annapolis, Maryland, Nov 15, 2011.

Sun Farm Oyster, LLC, "Design, construction, evaluation of hybrid (solar electric and wind) paddlewheel upweller" USDA grant: $93,458, http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/financial/cig/?&cid=stelprdb1044889

Van Voorhees, David and Lowther, Alan, "Fisheries of the United States, 2010," National Marine Fisheries Service, Office of Science and Technology, Fisheries Statistics Division, Silver Spring, Maryland, August 2011.

Vilnit, Steve, Maryland Department of Natural Resources, Fisheries Service, 2011Maryland Shellfish Aquaculture Conference, Doubletree Hotel, Annapolis, Maryland, Nov 15, 2011.

Wheeler, Timothy B., "Oyster farming off to a slow start in Maryland," *The Baltimore Sun*, June 20, 2011.

Wilberg MJ, Livings ME, Barkman JS, Morris BT, Robinson JM (2011) "Overfishing, disease, habitat loss, and potential extirpation of oysters in upper Chesapeake Bay," Mar Ecol Prog Ser 436:131-144, August 2011.