

UMCES Horn Point Laboratory  
Demonstration Oyster Farm

# Oyster Production Equipment Comparisons 2016–2018



This project and body of work reflect the combined efforts of a tireless group of dedicated individuals.

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Finally, Maryland's oyster growers deserve special mention for providing valuable insight for working on the water.

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# Oyster Production Equipment Comparisons 2016–2018

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## Abstract

The demonstration oyster farm at University of Maryland Center for Environmental Science (UMCES) conducted studies on a variety of contained culture equipment for a two-year period. The report provides information on commercially relevant aspects of oyster production associated with each equipment type employed. Unbiased information is provided on the various equipment types, allowing oyster growers to assess the tradeoffs associated with each equipment type. While acknowledging this study is limited to a single site, it suggests potential areas for future investigation.

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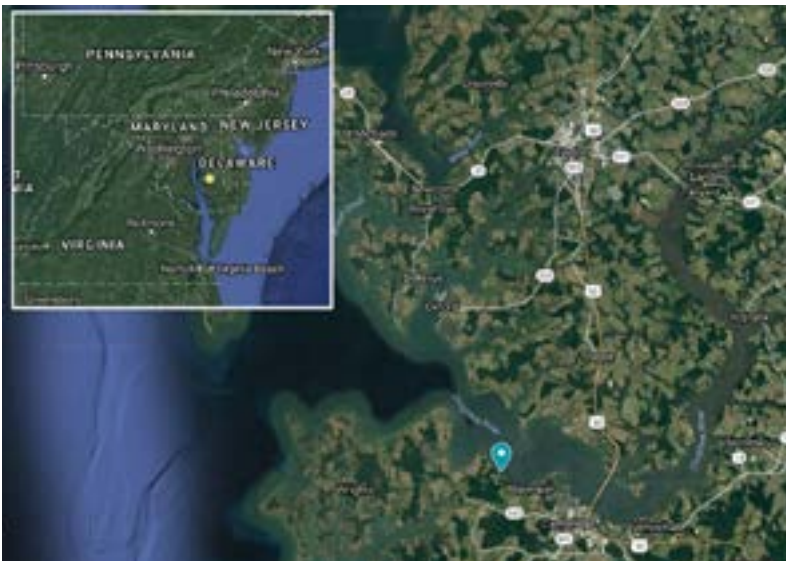
# INTRODUCTION

The revision of Maryland's shellfish leasing laws in 2009 has spurred interest in private oyster aquaculture, using both water-column and bottom leases for production. Interest in water-column leases utilizing containerized production equipment resulted in a need for research-based information on different equipment types in order to provide growers with unbiased information on equipment costs and oyster growth performance. Many equipment options are available, and research has been conducted on multiple equipment types in the Chesapeake Bay and elsewhere (see Davis, 2013; Gamble, 2016; Thomas et al, 2019; Walton et al., 2012). Given site specificity, additional comparative research into gear performance is warranted to aid current and prospective aquaculture operations in making business decisions. A lack of information has often left current and prospective shellfish aquaculture operators feeling unprepared to purchase equipment best suited to their needs. Often growers will use an equipment type that they have seen someone else use.

The University of Maryland Center for Environmental Science's (UMCES) Horn Point Laboratory (HPL) Oyster Hatchery, in cooperation with University of Maryland Extension (UME), with partial funding provided by Maryland Sea Grant, began a demonstration oyster farm (HPLDF) in 2016 to evaluate different oyster-aquaculture production equipment (Figure 1). The demonstration facility is located at the Broddus and Margaret Ann Jones Oyster Culture Facility at Horn Point, along the Choptank River, outside Cambridge, Maryland. (Figure 2).



**Figure 1.** UMCES Horn Point Laboratory demonstration oyster farm at mid-tide.



**Figure 2.** Demonstration farm location at UMCES Horn Point Laboratory (HPL) along the Choptank River in Maryland. The yellow dot in the small inset marks site location within the Mid-Atlantic region of the United States and blue dot in larger map represents specific location within the Choptank River.

The goal of the project is to provide information to current and prospective aquaculture oyster operations about available equipment types. The project has deployed five equipment types (see Appendix I for descriptions) and collects data on oyster production, including growth, condition index, worm infestation, and shell morphology. In addition to these biotic and physical measurements, economic data are captured on the cost of the equipment, installation costs, as well as labor requirements to build and install equipment. Information from this project will allow farmers to make informed decisions regarding purchases, operation, and lease management. Results at the HPLDF cannot be expected to apply to other sites, due to varying conditions and are site-specific for the given research period and area.

The HPLDF is also a UME training site, which provides individuals with opportunities to learn about equipment types at scheduled workshops and individual consultations. These interactions allow growers to work directly with equipment types before deciding whether to incorporate one or more methods in their production.

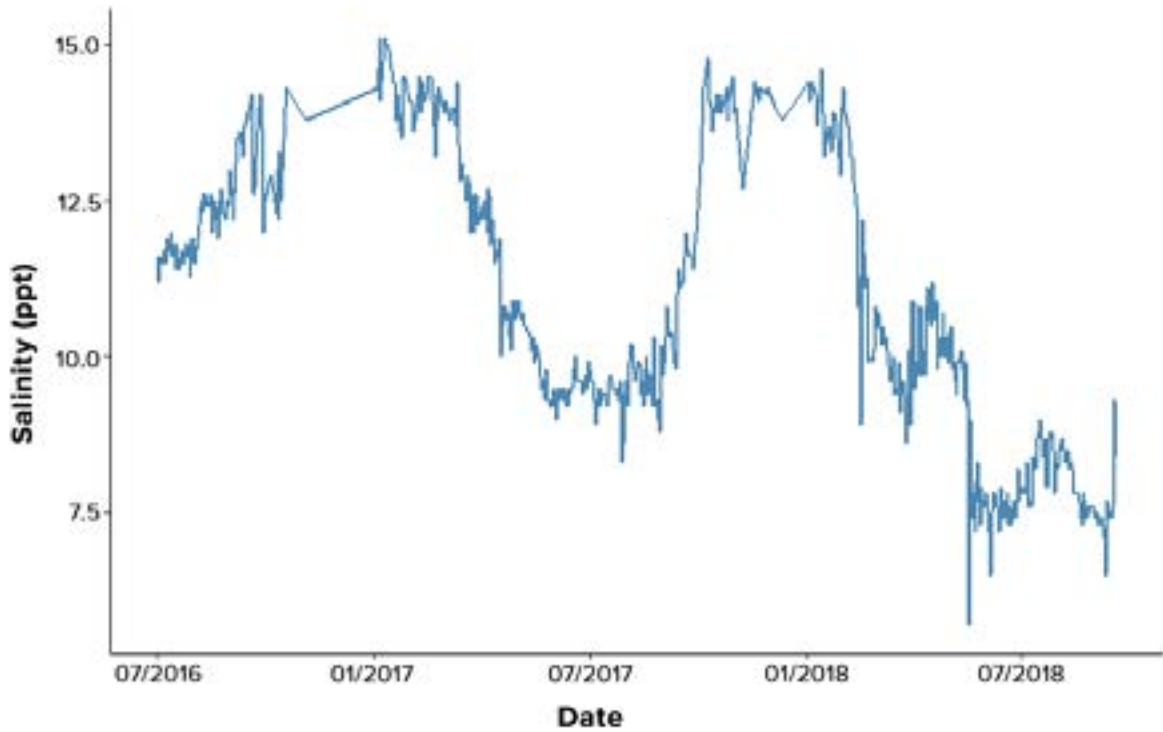
In this study, we present the results of the 2016–2018 growing season. Equipment in the study was purchased by the project. The types of equipment used do not represent all equipment available, and were selected based on commercial interest, site applicability, and logistical constraints. Neither UMCES nor its partners endorse any product included in the project and results are provided for informational purposes only.

## Methods

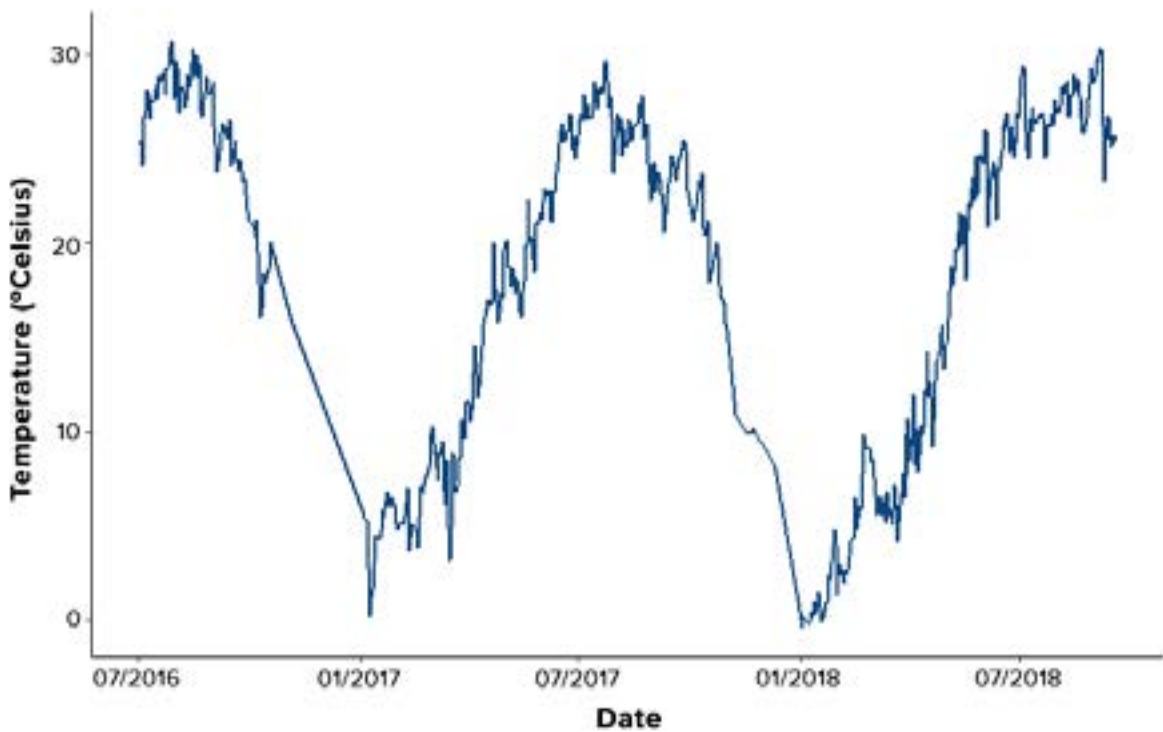
Research was conducted on containerized equipment available for intensive oyster culture. After consulting with current oyster aquaculture operations and assessing feasibility, five equipment types were selected for the farm. These include off-bottom, mid-water, and floating culture equipment. BST™ (used in crosshatch and longline orientations), OysterGro®, rack and bag, and Seapa™ equipment were selected based on interest from the industry. Appendix I provides images and descriptions of all equipment types employed. While the Virginia-style bottom cage is a popular equipment type in the Chesapeake region, it was not selected for inclusion in this study due to the lack of appropriate HPLDF equipment to hoist the large cages from the water.

## Site

The HPLDF is a one acre plot and served as the site for all equipment investigations (Figure 2). This site is located in the Choptank River, a tributary of the Chesapeake Bay (Figure 2). Average surface salinities in this site range from 10.1 to 12.5 (Wei, 2019), although salinities ranging from 4 to 16 parts per thousand (ppt) have been documented at the site (HPL Oyster Hatchery, unpublished data). During the period of study (2016–2018), salinity ranged from 6.5 to 15.1 (Figure 3) and ambient water temperature ranged from -0.4 to 30.7 °C (Figure 4). Site depth ranges from 1 to 4 feet (mean high water depth, NOAA Nautical Chart #12266) and experiences daily tidal fluctuations of approximately 1.5 feet. The site is fully protected from the south, and semi-protected from the west-northwest by a pier. The site is fully exposed to the north-northeast. Results obtained at this particular site cannot be expected to transfer to other sites.



**Figure 3.** Ambient salinity at the HPLDF site during the study period, 2016–2018.



**Figure 4.** Ambient water temperature (in degrees Celsius) at the HPLDF site during the study period, 2016–2018.

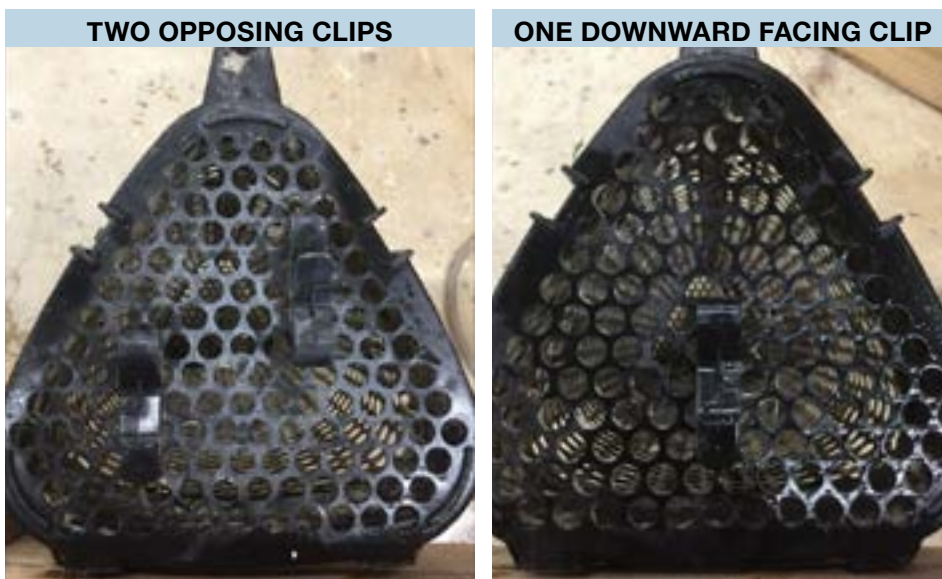
## Equipment

### BST™ Crosshatch (BST#)

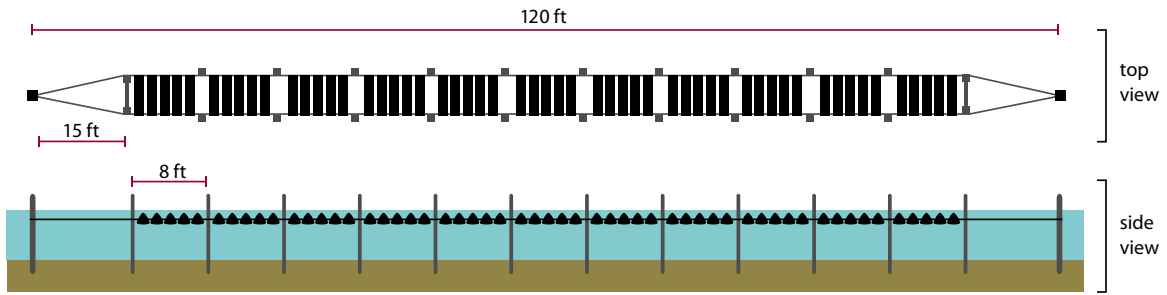
The BST™ Crosshatch (BST#) unit (Figure 5) is a mid-water, adjustable longline system with baskets holding oysters suspended on each end from an adjustable longline, with lines running along both sides of the basket. Longlines are heavy monofilament threaded through a rubber tube to minimize chafing, and are secured to pilings on each end. Each line is 120 feet long and is tensioned, with 5% of the total length pulled out of the line. Clips secure baskets to the lines, with two opposing clips on one end of the basket, and one downward facing clip on the opposite end of the basket (Figure 6). The system orientation emulates rungs on a ladder, where baskets are the rungs and lines provide the stiles (Figure 5). Baskets are situated perpendicular to the current to facilitate maximum flow through each with available mesh sizes of 6 or 12 mm. Baskets sit just above mean-low water level to allow twice-daily exposure to air during low tide. PVC posts affixed with clips at two heights support each line and allow the whole unit to be raised for longer periods of desiccation. In this project, oysters were desiccated during each low tide and for 24 consecutive hours per week, with the exception of winter months.



**Figure 5.** BST™ Crosshatch (BST#) undergoing weekly desiccation at the Horn Point Laboratory demonstration oyster farm in the Choptank River.



**Figure 6.** Proper configuration of clips on each end of BST™ Crosshatch baskets.



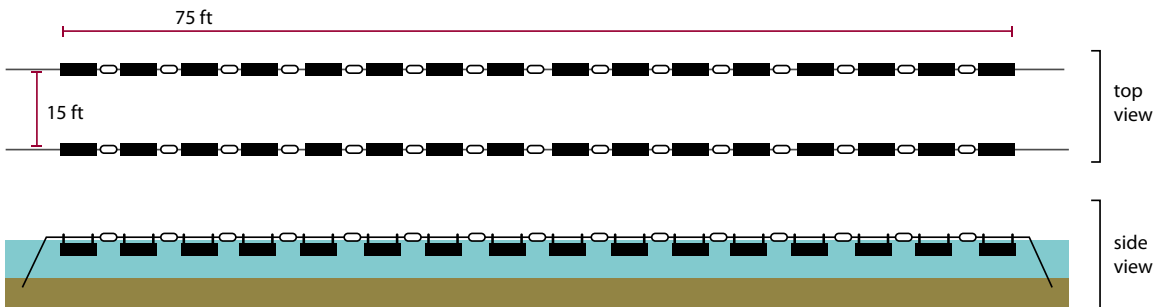
**Figure 7.** BST™ Crosshatch configuration

### BST Longline

The BST™ Longline (BST LL) system (Figure 8) is a mid-water equipment with baskets holding oysters suspended from a single line secured with two hooks on top of the units. Baskets are placed perpendicular to the current for maximum flow and available basket mesh sizes are 6 mm and 12 mm. Longlines securing the baskets are the same as the Crosshatch system. The system can be installed as a tensioned adjustable longline system allowing for desiccation. However, it was not set up in this manner due to the cost required for additional pilings, which make pilings unfeasible for many farms. For this project, baskets were floated at the surface using buoys between each unit and baskets remained subtidal.



**Figure 8.** BST™ Longline (BSTLL) basket with clips along the top that hang from a single floating line.



**Figure 9.** BST™ Longline configuration.

## OysterGro

OysterGro® (OG) (Figure 10) is a floating cage that can hold up to six Vexar® bags (Figure 11). Two pontoons provide flotation to the cage. Cages are attached to nylon rope anchored by 54-inch double helix screw augers at each end. Units are attached to the nylon rope using guy-lines and swordfish/longline clips (Figure 12). Units can be inverted to allow the cage to sit on top of the pontoons for aerial desiccation. The inverted position can also be used during periods of strong storms or winter ice to sink the cages. The units can be flipped with end caps removed from the pontoons, allowing them to fill with water and sink. After the weather event, cages can be returned to the surface to resume flotation. In this project, the OysterGro® units were desiccated for 24 consecutive hours per week, with the exception of winter months.



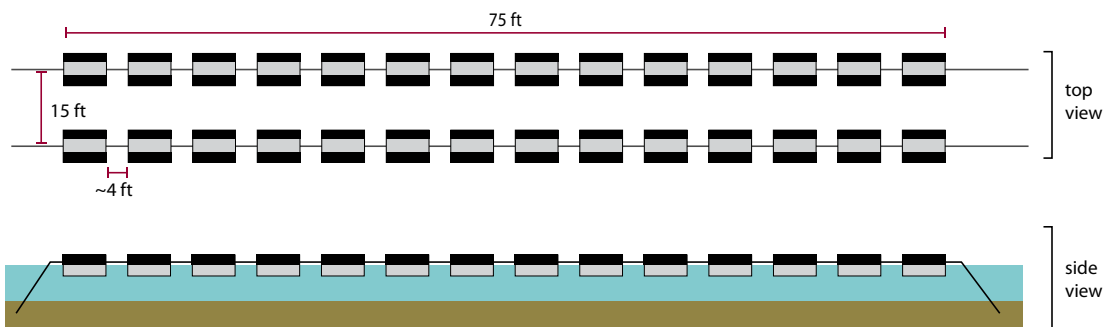
**Figure 10.** OysterGro® unit on land. Two pontoons along the top of the cage provide flotation for the cage that houses Vexar® bags of oysters.



**Figure 11.** Vexar® bag can be filled with oysters. Numerous mesh sizes are available and the bags can be boxed (as seen here) or left in a “pillow” style.



**Figure 12.** Swordfish/longline clips to secure OysterGro® cages and guy-lines to anchored longline.



**Figure 13.** OysterGro® configuration.

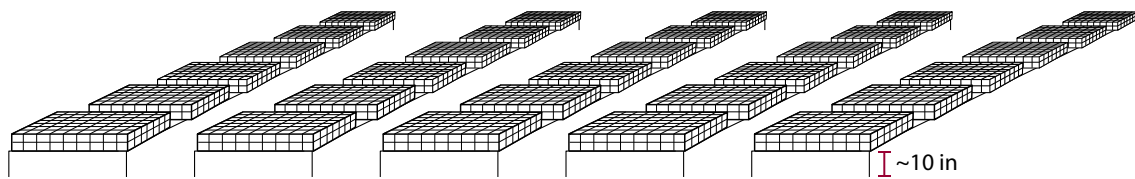


## Rack and Bag

Rack and bag (RB) (Figure 14) is an off-bottom system using Vexar® bags secured to reinforcing bar rack frames. The bags sit approximately 10 inches off the bottom while rubber tarp straps secure the corners of the bags to the rack. In regions with greater tidal flux, these can be intertidal systems, but in this project, the bags remained subtidal.



**Figure 14.** Rack and bag system (miniature version). Commercial racks house six bags and keep the bags approximately 10 inches off the seafloor.



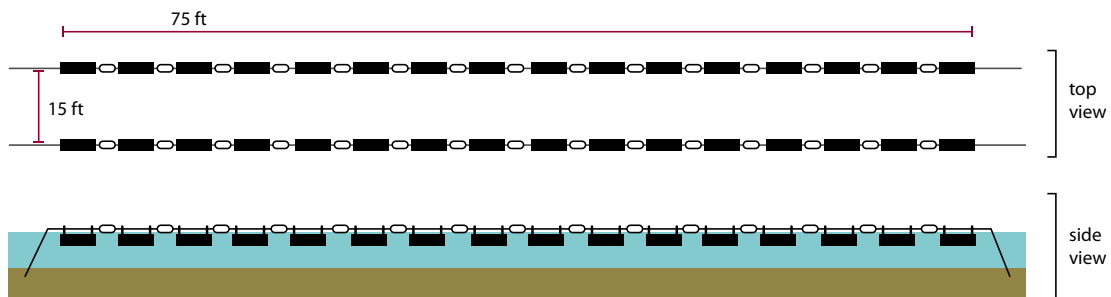
**Figure 15.** Rack and bag configuration.

## Seapa

Seapa™ (SE) (Figure 16) is a mid-water longline system consisting of baskets that hold oysters suspended from a single line. Baskets are suspended from the line by two hooks on top of each basket. Lines are oriented perpendicular to the current to allow maximum flow through each basket. Mesh sizes include 3 mm, 6 mm, 12 mm, and 24 mm sizes. As with the BST™ system, it has the ability to be installed as a tensioned longline to allow desiccation, however, they were not set up that way for this project. Baskets were floated from the surface using can buoys between each unit and baskets remained subtidal.



**Figure 16.** Seapa™ unit on land, with clips along the top of the basket to secure the basket to a single, floating line.



**Figure 17.** Seapa™ configuration.

## Oyster Production

Diploid hatchery reared oyster (*Crassostrea virginica*) seed of the same brood and set (source: Shoal Creek, set date: March 10, 2016, size at deployment 3–10 mm) (Figure 18) were deployed to each equipment treatment in July of 2016 (Table 1).



**Figure 18.** Juvenile oyster seed being deployed to the HPL demonstration oyster farm in July 2016.

**Table 1.** Total number of oysters deployed to each equipment treatment.

Equipment Type	Total Oysters Stocked
Seapa™	6,400
Rack and Bag	6,000
OysterGro®	36,000
BST™ Longline	6,400
BST™ Crosshatch	40,000

Oysters remained in their original equipment treatments throughout the analysis, except during winter months when they were labeled, containerized, and sunk in the deep portion of the farm for protection. The site experiences extremely low tides in winter that would have led to prolonged exposure to freezing temperatures potentially killing the oysters (Figure 19). Each spring, oysters were returned to their original culture units.



**Figure 19.** Example of winter low tide at HPL demonstration oyster farm site.



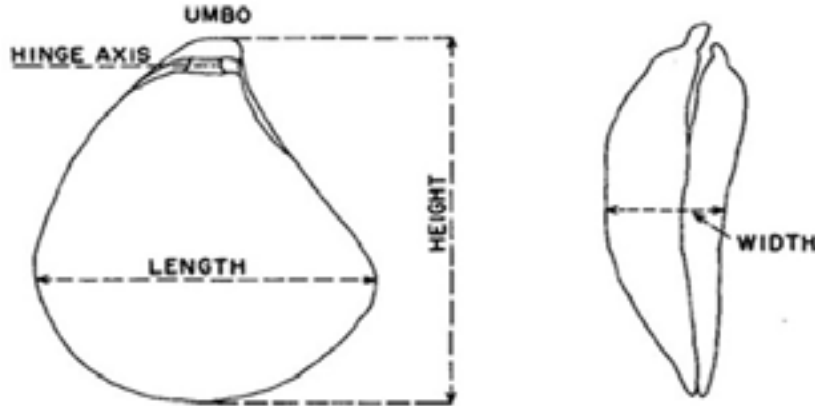
**Figure 20.** Oyster tumbler used at six-week intervals during processing.

Every six weeks from April through November, the oysters were removed from the water for processing. Processing consisted of tumbling oysters in a 48-inch tube (Figure 20), power-washing culture equipment, and re-stocking oysters in their respective equipment types.

Densities were maintained at ~33% of the interior volume of each equipment type. This resulted in an unequal number of oysters per unit, but ensured a consistent ratio of oysters to interior container volume between equipment types. This method is common in the industry to maintain stocking density. Fifteen liter Seapa™ and BST™ baskets were stocked at 5 liters per cage, and 37-liter Vexar® bags were stocked at 12 liters per bag.

## Data Collection

Thirty randomly selected oysters were measured from each treatment every three weeks, excluding winter months. Shell height (hinge to bill) was recorded to the nearest millimeter. In 2017 and 2018, shell length (across the right valve of the oyster) and width (cup of the oyster), were measured in addition to height. Figure 21 depicts the measurement regime.



**Figure 21.** Oyster height, length, and width measurements. From Galtsoff, 1964.

Shell height was measured to calculate total oyster growth since deployment and net growth per year for each equipment type. Shell length, width, and height were also measured to quantify shell morphology analysis (Width Index, Galtsoff Shape Index and 3:2:1 Ratio). The width index describes a ratio of oyster shell length to height and is calculated as:

$$\text{Width Index} = \frac{\text{Shell Length}}{\text{Shell Height}}$$

The Galtsoff Shape Index Method (Ward et al., 2005) was calculated as:

$$\text{Galtsoff Shape Index} = \frac{\text{Shell Height} + \text{Shell Width}}{\text{Shell Length}}$$

A 3:2:1 ratio of shell height to length to width, respectively, has been suggested as optimum for oyster shape (Brake et al., 2003, Mizuta and Wikfors, 2018, Thomas et al., 2019). Oyster morphology was analyzed using a chi-squared deviation to determine how closely the oysters fit this 3:2:1 ratio of shell height to length to width. A “perfectly” shaped oyster would not deviate from this 3:2:1 fit.

Condition index was measured in September 2018 according to Hopkin’s Formula (Lawrence & Scott, 1982):

$$\text{Condition Index} = \frac{\text{Dry Meat Weight (g)} \times 100}{\text{Internal Cavity Volume (cm}^3\text{)}}$$

Whole oysters were removed from the water, scrubbed free of external biofouling organisms, and then allowed to dry in ambient laboratory air conditions for 60 minutes. The oysters were weighed (in grams), then shucked, and the weight of valves (in grams) was recorded. Cavity volumes were measured by subtracting the weight of valves from whole oyster weight. Density of the cavity contents has been previously measured as 1 g per cm<sup>3</sup> (Lawrence & Scott, 1982). Dry meat weight of all oyster tissue (in grams) was recorded after being dried in an oven at 68°C for 48 hours.

Multiple species of worms are associated with oyster culture (Blake and Evans, 1973) and at least one, *Polydora websteri*, can affect the growth and the condition index of aquaculture oysters (Gryder, 2002; Read, 2010; Wargo et al., 1993). Due to the inability to quantify the number of worms per oyster via visual inspection, trials were conducted to identify the most effective method for the expulsion of burrowing worms. An effective solution to expel worms for quantification was identified as a 24-hour bath in a solution of 5% ethanol and 95% artificial seawater (13 ppt/psu) (Figure 22). Oysters from each equipment type were submerged in individual jars containing this solution, and the expelled worms were counted after the 24-hour immersion.<sup>1</sup>



**Figure 22.** Worms expelled from oysters after a 24-hour exposure to a 5% ethanol solution. Worms vacate their burrows in oyster shells and are visible for counting. This solution is not approved for commercial use on oysters destined for consumption and is conducted here for research purposes only.

## Statistical Analysis

Statistical analyses were conducted in RStudio (version 3.4.1/2017-06-30) using either an Analysis of Variance (ANOVA) or a non-parametric Kruskal Wallis rank sum test. Normally distributed data were analyzed with an ANOVA to assess differences among equipment types, and significant findings ( $p < 0.05$ ) were further investigated using Tukey's Honest Significant Difference Test. Some data were not normally distributed, therefore the Kruskal Wallis rank sum test was used for these data sets (analysis of shell-height growth data, 3:2:1 ratio and condition index). Pairwise comparisons of non-normally distributed data were conducted using Dunn's test for multiple comparisons (package FSA, version 0.8.22.9000) and multiple comparisons were corrected using the Holm method (package FSA, version 0.8.22.9000).

Box and whisker plots were used to graphically display data. These plots consist of a box, with the thick middle line representing the median value of the data, and the top and bottom of each box representing the 25% (lower) and 75% (upper) bounds of the interquartile range. Vertical lines extending above and below each plot indicate the distribution of the data to  $\pm 1.5$  (1.5 x the interquartile range). Any black dots included above or below the plot represent outliers that fall outside of  $\pm 1.5$  (1.5 x the interquartile range) (Wickham, 2016).

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<sup>1</sup> This solution is not approved or suggested for commercial use and may not be applied to oysters destined for human consumption

# RESULTS

## Oyster Survival

Oyster survival to the end of the study period varied among equipment types. The 2016 and 2017 growing seasons were characterized by typical salinity conditions for the Choptank River, but record rainfall led to decreased salinity in 2018. Such reduced salinity may have resulted in increased mortality during the 2018 season. In addition to removing oysters that died during the study period, oysters were also removed to maintain volumetric stocking densities as previously described. Market size (three inch) oysters were removed from the BST™ Crosshatch system before the end of the study period. These oysters were counted in the survival calculations.

**Table 2.** Cumulative oyster survival by equipment type during the period 2016–2018.

Equipment Type	Oysters Deployed	Oysters Harvested	% Survival
Seapa™	6,400	1,863	29%
Rack and Bag	6,000	3,840	64%
OysterGro®	36,000	14,476	40%
BST™ Longline	6,400	2,288	36%
BST™ Crosshatch	40,000	18,828	47%

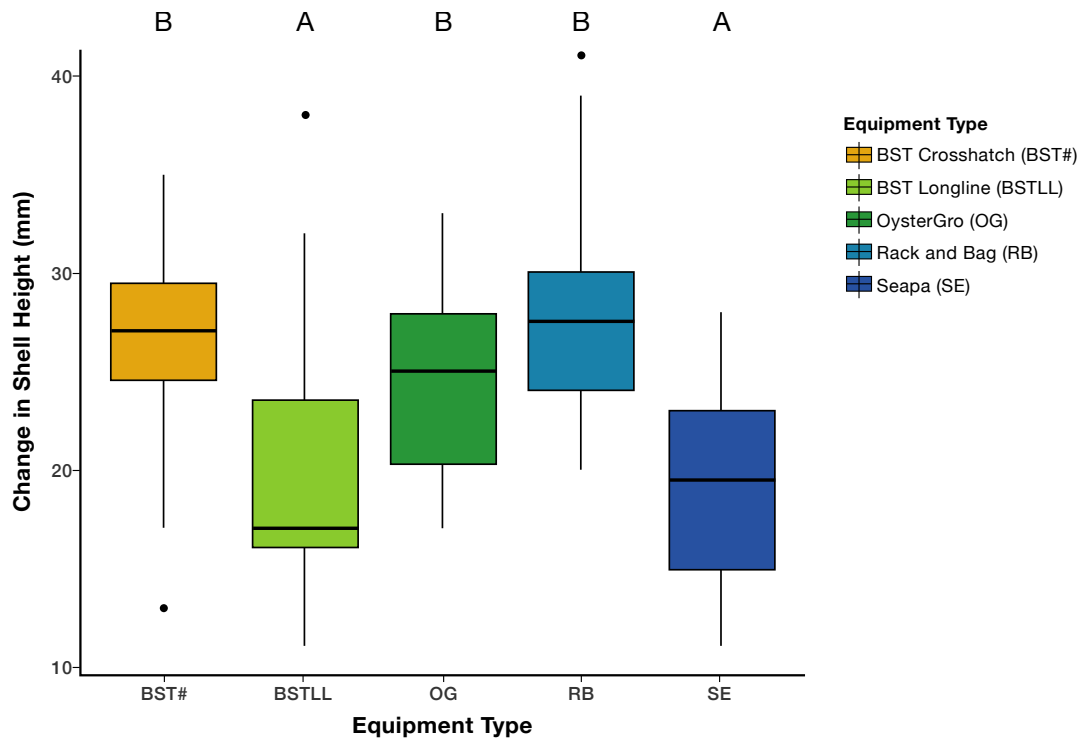
## Oyster Growth by Season

### 2016: Shell Height Growth (hinge to bill)

The rack and bag system yielded the most growth (in shell height) during the 2016 season, followed closely by the BST™ Crosshatch and OysterGro®. The rack and bag, BST™ Crosshatch and OysterGro® systems each attained significantly greater shell height ( $p < 0.05$ ) than the BST™ Longline and the Seapa™ systems in 2016. (Figure 23, Table 3).

**Table 3.** Average change in shell height (in mm) per year for oysters grown in five equipment types 2016–2018.

Equipment Type	Mean change in shell height (mm) since deployment		
	2016	2017	2018
BST Crosshatch	27.1	39.7	46.9
BST Longline	19.4	45.7	51.7
OysterGro®	24.9	35.7	41.4
Rack and Bag	27.8	53.8	60.0
Seapa™	19.8	43.3	61.2

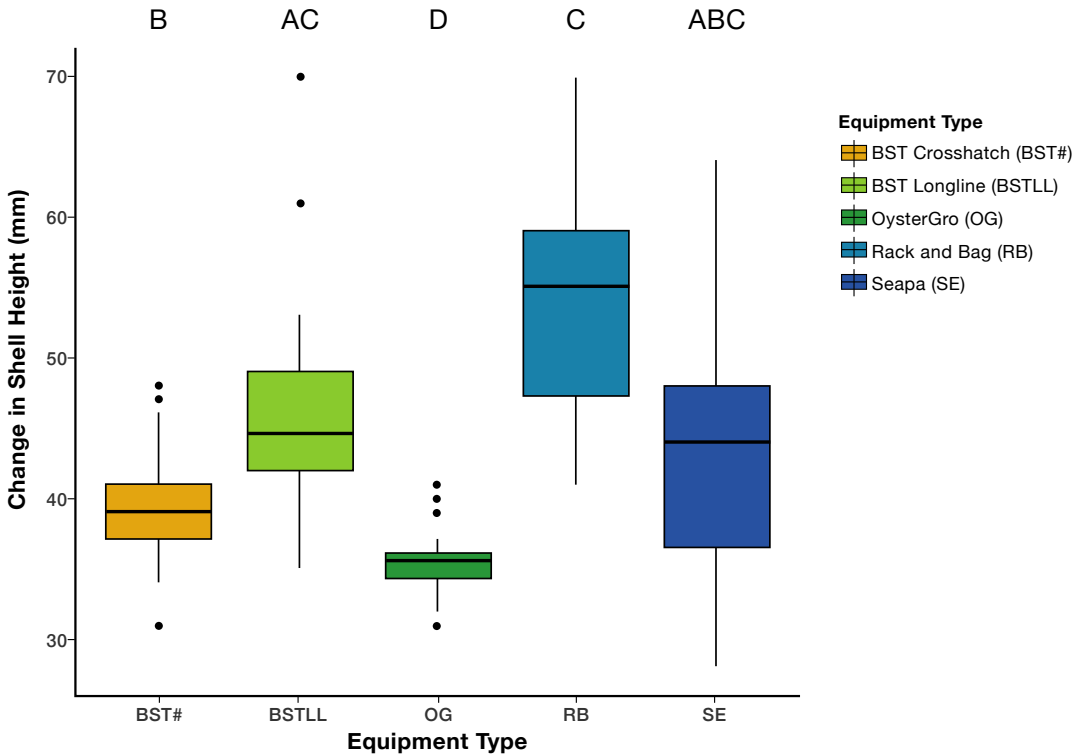


**Figure 23.** Box and whisker plot depicting the change in shell height (in mm) of oysters grown in five equipment types in between July and November of 2016. The thick line in the middle of each box represents the median (middle) value of the data. Letters represent significance groups; no significant differences were observed among treatments with letters in common.



## 2017: Total Growth Since Deployment

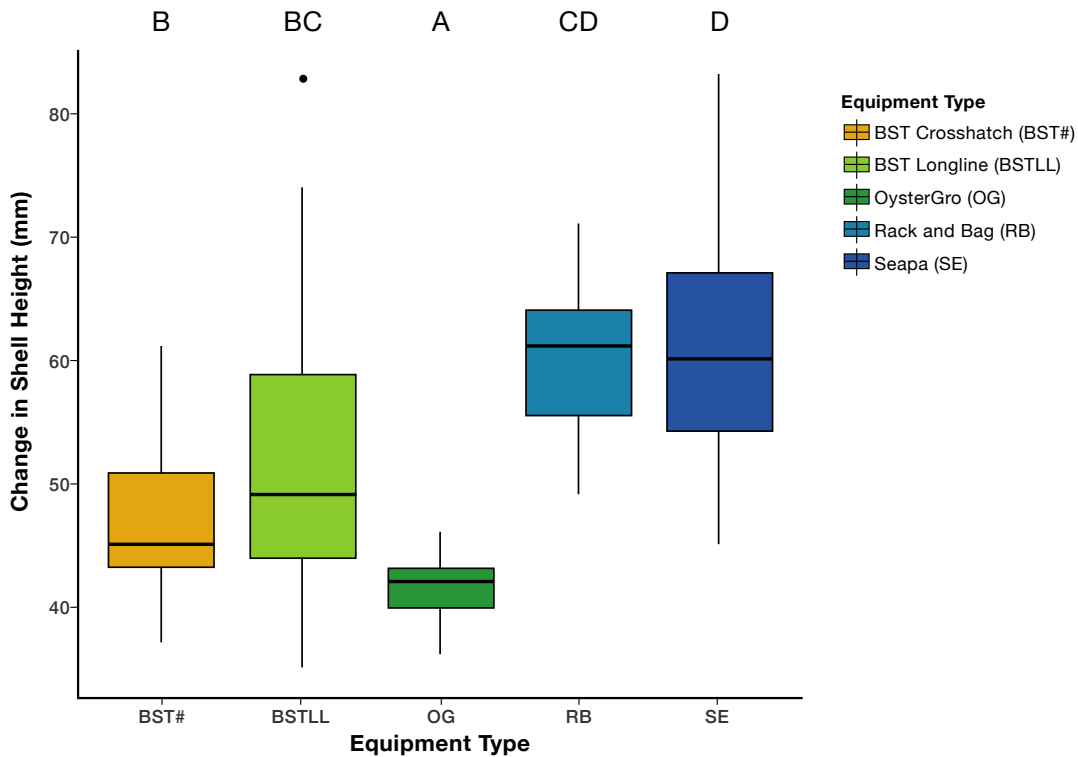
The rack and bag system yielded the most growth in shell height at the end of the 2017 season, followed by BST™ Longline and Seapa™. Oysters from the rack and bag and BST™ Longline attained significantly greater shell height during this period ( $p < 0.05$ ) than oysters from BST™ Crosshatch and OysterGro® units. Oysters grown in Seapa™ units reached significantly greater shell height than oysters in OysterGro® ( $p < 0.05$ ) (Figure 24, Table 3).



**Figure 24.** Box and whisker plot depicting the total change in shell height (in mm), as of November 2017, of oysters grown in five equipment types since their July 2016 deployment. The thick line in the middle of each box represents the median (middle) value of the data. Letters represent significance groups; no significant differences were observed among treatments with letters in common.

## 2018: Total Growth Since Deployment

The Seapa™ system yielded the most growth (in shell height) at the end of the 2018 season, followed by rack and bag and BST™ Longlines. Oysters grown in the OysterGro® system yielded the least growth (in shell height) at the end of the 2018 season. Oysters in the Seapa™ system attained significantly greater shell height than oysters in BST™ Crosshatch, BST™ Longline, and OysterGro® ( $p < 0.05$ ). Oysters in BST™ Crosshatch and BST™ Longline units yielded significantly greater shell height than oysters in OysterGro® ( $p < 0.05$ ) (Figure 25, Table 3). An overall assessment of growth throughout the duration of this project is included in Figure 26 along with ambient salinity over the period<sup>2</sup> (Figure 3). Photographs were taken of oysters grown in each equipment type: BST™ Crosshatch (Figure 27), BST™ Longline (Figure 28), OysterGro® (Figure 29), rack and bag (Figure 30) and Seapa™ (Figure 31).



**Figure 25.** Box and whisker plot depicting the total change in shell height (in mm), as of September 2018, of oysters grown in five equipment types since their July 2016 deployment. The thick line in the middle of each box represents the median (middle) value of the data. Letters represent significance groups; no significant differences were observed among treatments with letters in common.

<sup>2</sup> Rainfall in 2018 was abnormally high, resulting in lower than normal salinities. This lower salinity may have affected oyster growth in all systems.

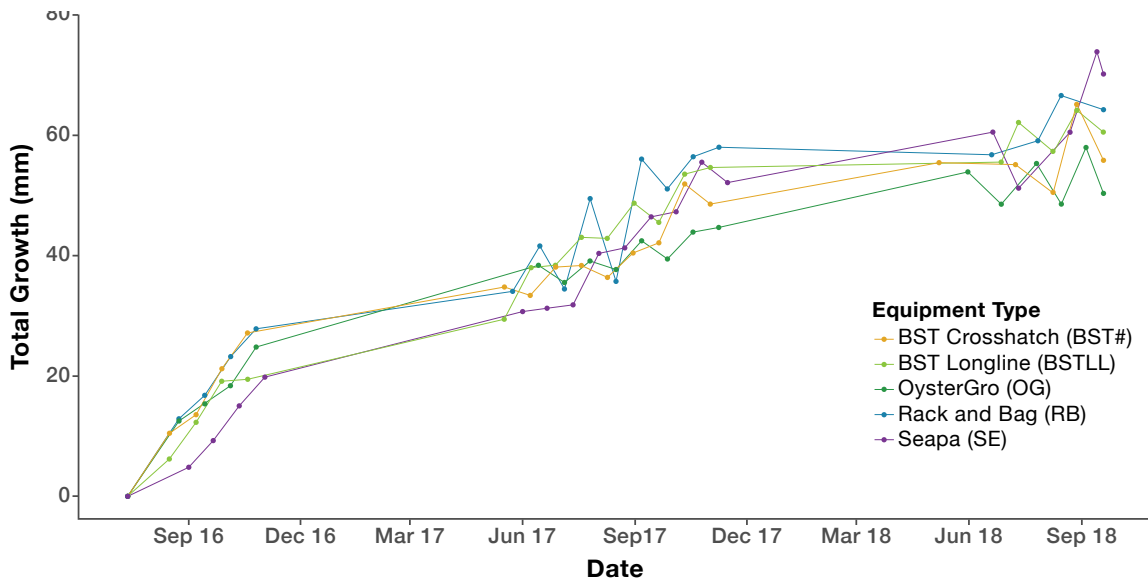


Figure 26. Line plot depicting the growth (in mm) of oysters grown in five equipment types from 2016–2018.



Figure 27. Random sample of oysters grown in the BST™ Crosshatch method as of September 2018.



**Figure 28.** Random sample of oysters grown in the BST™ Longline method as of September 2018.



**Figure 29.** Random sample of oysters grown in the OysterGro® system as of September 2018.



Figure 30. Random sample of oysters grown in the rack and bag system as of September 2018.

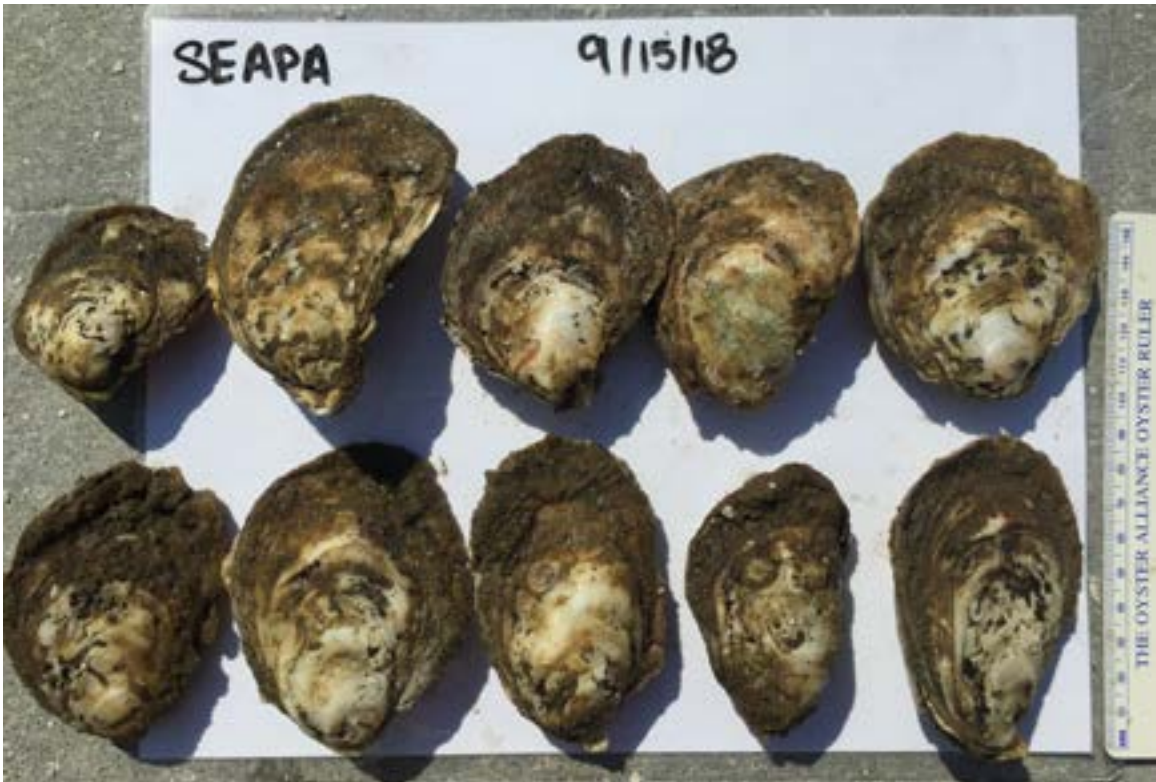


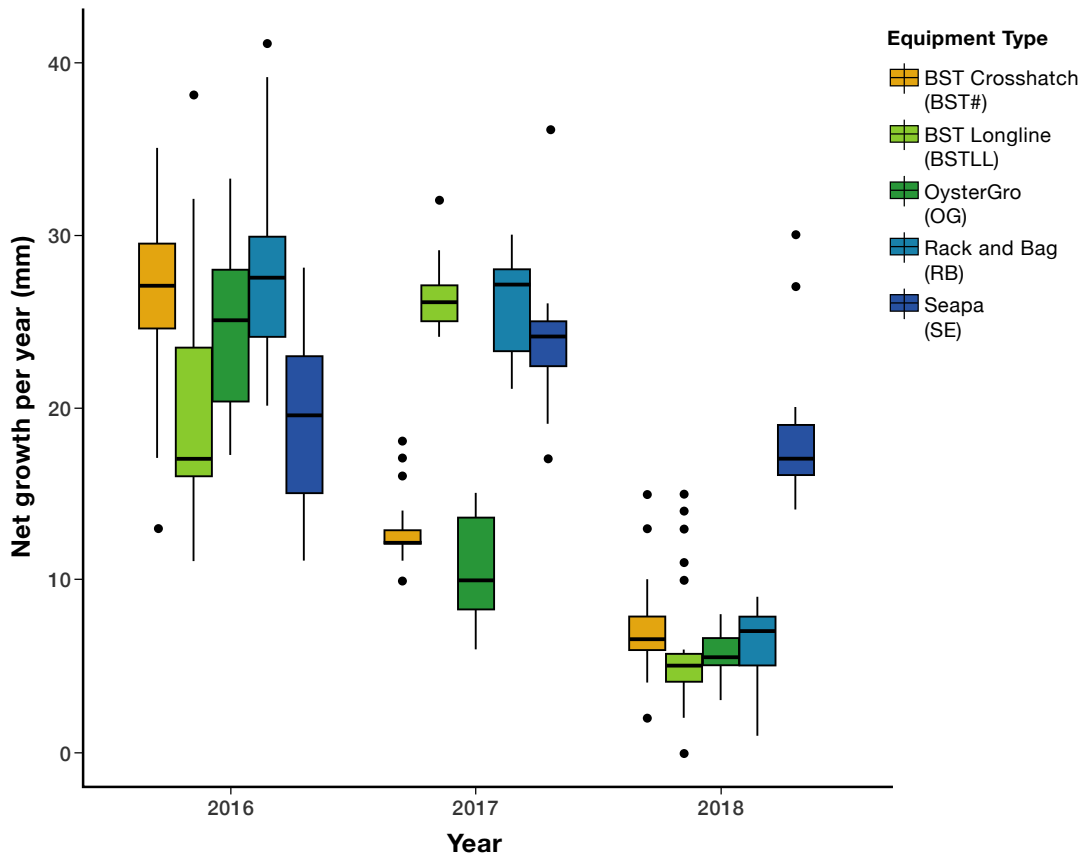
Figure 31. Random sample of oysters grown in the Seapa™ system as of September 2018.

## Net Growth Per Year

Net growth per year was calculated as the change in shell height each year (Figure 32, Table 4). In 2016, rack and bag yielded the highest net growth. In 2017, BST™ Longline yielded the highest net growth. In 2018, Seapa™ yielded the highest net growth. The 2016 and 2017 growing seasons were characterized by typical salinity conditions for the Choptank River, but record rainfall led to decreased salinity in 2018 (Figure 3). Such reduced salinity may have resulted in reduced growth during the 2018 season.

**Table 4.** Net growth per year of oysters grown in five equipment types at the HPL demonstration oyster farm.

Culture Method	2016 growth (mm)	2017 growth (mm)	2018 growth (mm)
BST™ Crosshatch	27.1	12.7	7.2
BST™ Longline	19.4	26.3	6.0
OysterGro®	24.9	10.8	5.7
Rack and Bag	27.8	25.9	6.3
Seapa™	19.8	23.5	17.9



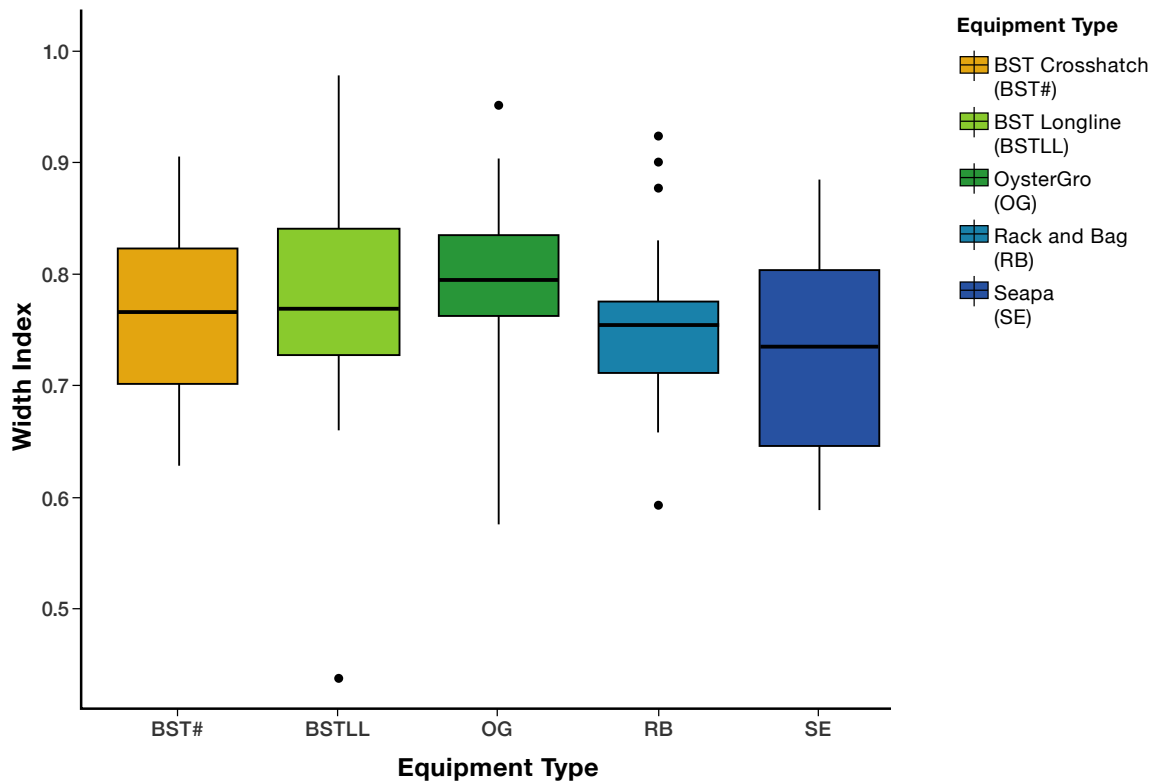
**Figure 32.** Average net growth per year of oysters grown in five equipment types at the HPL Demonstration Farm. The thick line in the middle of each box represents the median (middle) value of the data.

# Shell Morphology

Oyster height, length, and width (Figure 21) were measured for oysters grown in each culture method. Three analyses were used to quantify shell morphology.

## Width Index

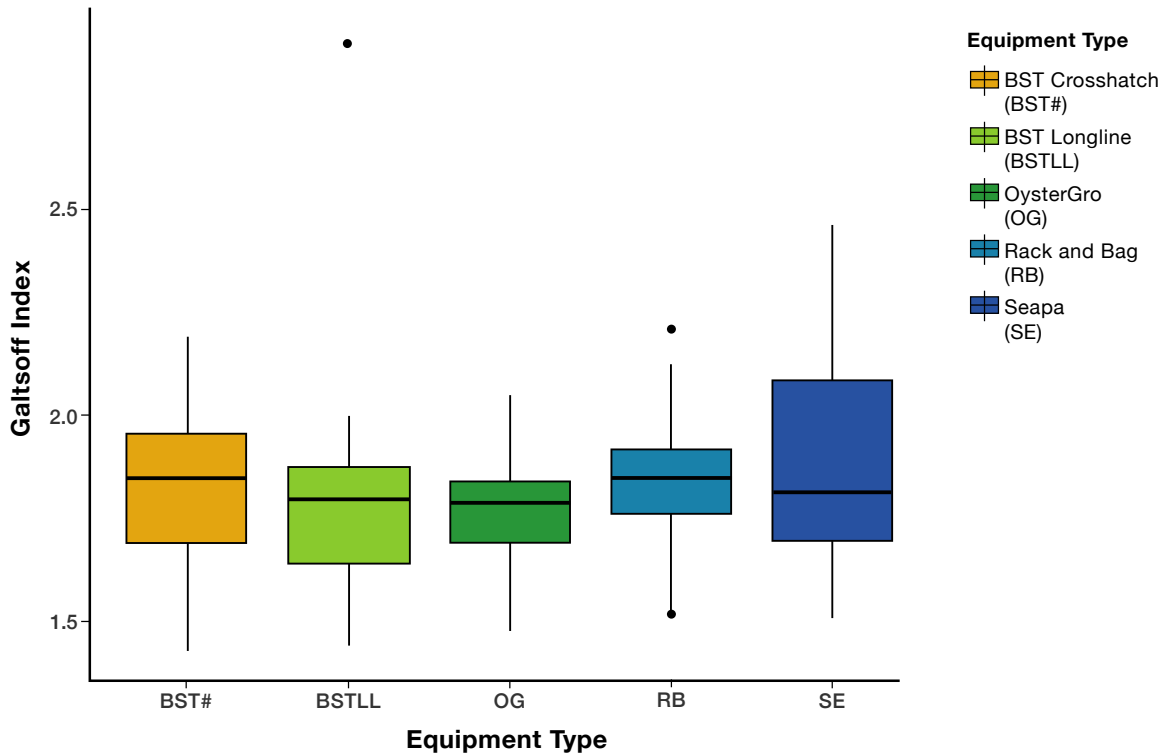
Width indices greater than 0.63 indicate more favorably shaped oysters (Brake et al., 2003). Oysters grown in OysterGro® were more favorably shaped than those grown in the Seapa™ system ( $p < 0.05$ ). Other significant relationships were not found among other methods, but all yielded favorably shaped oysters (Figure 33).



**Figure 33.** Box and whisker plot depicting the Width Index of oysters grown in five equipment types. Width index is calculated as the ratio of oyster length to oyster height. Width Indexes  $> 0.63$  indicate more favorably shaped oysters. The thick line in the middle of each box represents the median (middle) value of the data.

## Galtsoff Shape Index

Ward et al., (2005) suggested scores less than three indicate good oyster shape; scores of three indicate average oyster shape, while scores greater than three indicate poor oyster shape. Oysters grown in each method yielded scores well below three, indicating that culture methods displayed good shape with no significant differences observed among equipment types (Figure 34).



**Figure 34.** Box and whisker plot depicting the Galtsoff Index for oysters grown in five equipment types. A Galtsoff Index of less than three has been suggested to be indicative of a favorable shape. The thick line in the middle of each box represents the median (middle) value of the data.

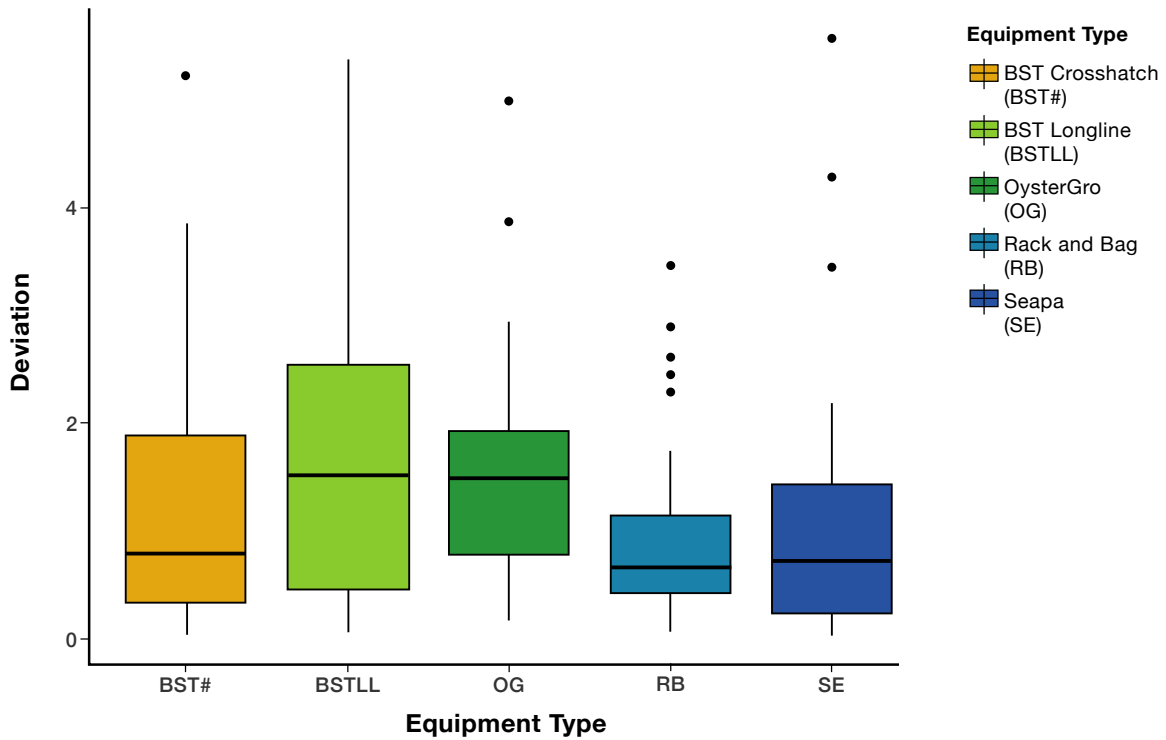
## 3:2:1 Ratio

Shell morphology was assessed as the ratio of shell height:length:width. Oysters grown in all equipment types deviated from ideal fit but no significant differences were observed among equipment (Figure 35).

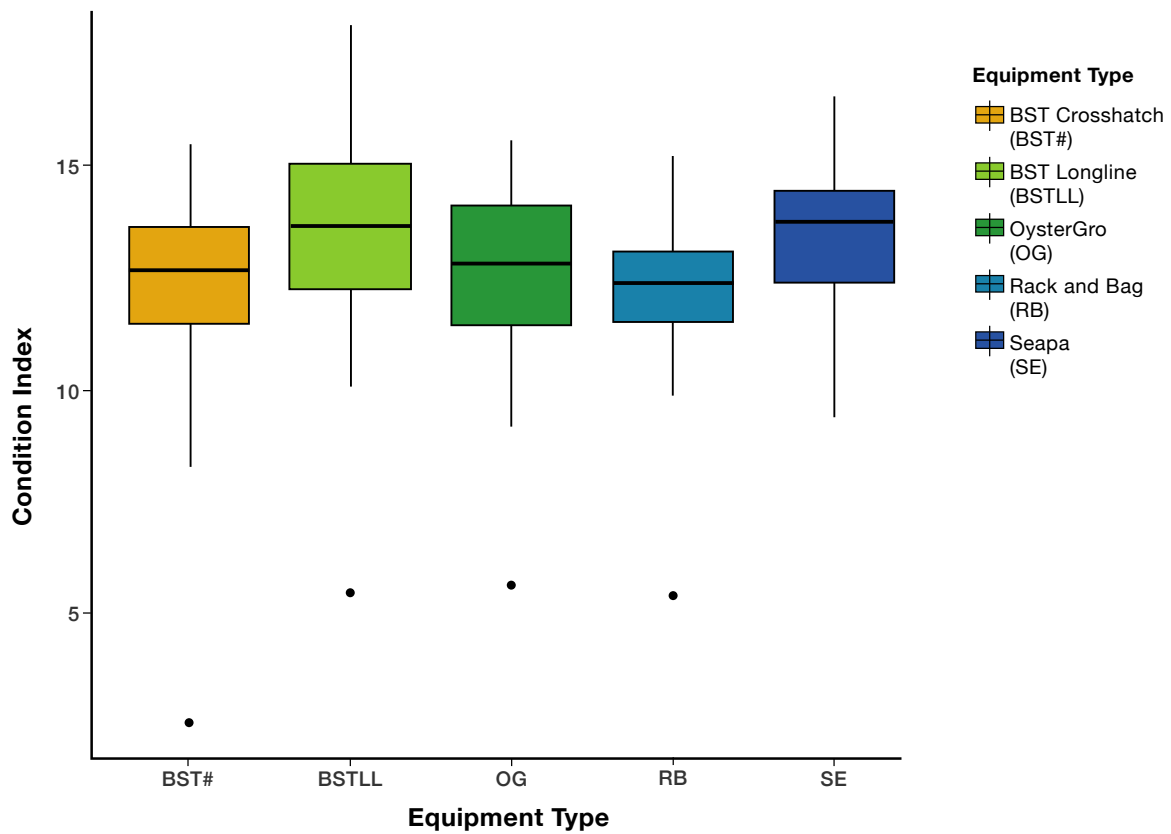
## Condition Index

Condition Index for oysters in each of the five equipment types was calculated in November 2018. Significant differences among systems were observed, with the Seapa™ and BST™ Longline systems yielding improved condition index values compared to the rack and bag oysters ( $p < 0.05$ ) (Figure 36).





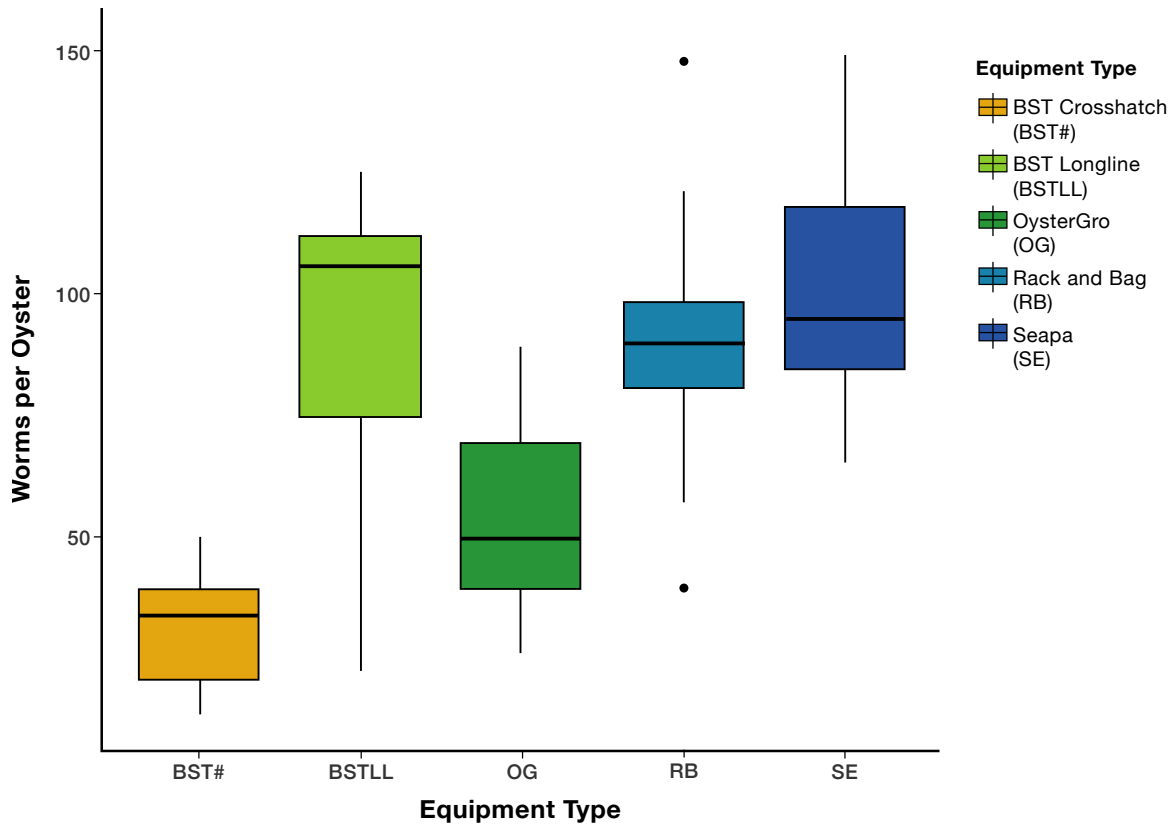
**Figure 35.** Box and whisker plot depicting the deviation from idealized 3:2:1 shape ratio of oysters grown in equipment types. Deviation of zero indicates an ideally shaped oyster. The thick line in the middle of each box represents the median (middle) value of the data.



**Figure 36.** Box and whisker plot depicting the condition index values of oysters grown in five equipment types. The thick line in the middle of each box represents the median (middle) value of the data.

# Worm Presence

Oysters in each equipment type were analyzed for the presence of burrowing worms. BST™ Crosshatch and OysterGro® yielded the fewest worms per oyster, while BST™ Longline, Seapa™, and rack and bag yielded a significantly greater number of worms ( $p < 0.05$ ) (Figure 37). BST™ Crosshatch and OysterGro® systems underwent regular desiccation while the others remained subtidal, which likely reduced worm presence in BST™ Crosshatch and OysterGro®. Reduced worm infestations in BST™ Crosshatch and OysterGro® are likely due to the desiccation treatment rather than the equipment itself.



**Figure 37.** Box and whisker plot noting the number of worms expelled from oysters grown in each of five equipment types. The thick line in the middle of each box represents the median (middle) value of the data.

# Cost Estimates

## Capital Costs and Installation

The cost of installing different oyster grow out systems used on the farm was recorded. In addition to the cost of equipment and associated materials needed to install the system (Table 5), labor was recorded for installation, and assembly of different equipment types. A more detailed breakdown of capital and installation costs can be found in Appendix II. Equipment should last for multiple growing seasons dependent on site conditions.

**Table 5.** Capital costs associated with each equipment treatment.

Equipment Type	Capital & Installation Costs
Seapa™	\$3,175.46
Rack and Bag	\$1,800.05
OysterGro®	\$6,068.80
BST™ Longline	\$2,308.34
BST™ Crosshatch	\$20,465.08

Total capital costs were highest for the BST™ Crosshatch system due to the installation of pilings to support the system. There may be other materials available to support the BST™ Crosshatch system resulting in lower overall installation costs. The costs associated with installing the BST™ Crosshatch system minus the cost of piling installation totaled \$8,465, which is higher than capital costs associated with the other equipment evaluated. Due to the configuration of the BST™ Crosshatch system, more baskets were purchased to complete the system than the BST™ Longline system. The additional baskets increased the overall capital costs when compared to other equipment treatments. Total capital costs were lowest for the rack and bag system. All potential equipment and installation costs should be considered for any oyster production system before making a final decision.

## Production Costs

Costs associated with seed, maintenance, and labor were recorded for each equipment treatment, assuming workers are paid \$15 per hour. Cost of production based on these items was determined by dividing the total cost by the number of oysters in each equipment treatment at the end of the study period (Table 6). Costs associated with electricity and fuel for tumblers and power washers were not collected. A more detailed breakdown of costs can be found in Appendix II.

**Table 6.** Estimated cost of production for oysters from each equipment treatment.

Equipment Type	Oysters Harvested	% Survival	Production Variable Cost	Production Cost per Oyster
Seapa™	1,863	29%	\$1,089.90	\$0.59
Rack and Bag	3,840	64%	\$573.00	\$0.15
OysterGro®	14,476	40%	\$4,707.00	\$0.33
BST™ Longline	2,288	36%	\$768.15	\$0.34
BST™ Crosshatch	18,828	47%	\$6,939.00	\$0.37

Oysters produced in the Seapa™ system had the highest cost of production, while those produced in the rack and bag system had the lowest cost of production. Due to the experimental nature of this project, oysters were handled and processed more often than would be expected on a commercial farm. Each processing event likely took longer due to measuring individual oysters and restocking at consistent volumes. Caution should be exercised when using the production cost per oyster as all costs were not collected (i.e., electricity, equipment fuel, costs associated with labor beyond wages), which would alter these numbers in a commercial setting. However, the costs presented give a general idea of the production cost for each equipment type.

# DISCUSSION

Many factors should be considered when planning an oyster aquaculture operation. Growth, condition index, morphology, and worm presence are factors farmers should consider in managing their businesses. Inputs including supplies, labor, and equipment are critical in maintaining profitability. In addition, the demands of the intended markets are key factors to consider. This study has shown there are differences in morphology for oysters depending on the equipment used for grow out. In addition, there are differences in the capital and installation costs associated with each equipment type. As noted in Parker et al. (2020), labor is a significant cost when producing oysters in the water column in Maryland. Production costs varied among equipment types primarily based on labor associated with routine maintenance and desiccation of oysters in various systems.

## **BST™ Crosshatch**

### **Installation and Operation Notes**

Installation of the BST™ Crosshatch system required a large up-front capital investment, a permitting process, and the use of a contractor with specialized equipment to install the pilings. Following installation of the pilings, lines were installed using a come-along and Klein grip, which are readily available and do not require specialized training. Basket construction is made much easier when the baskets can warm in the sun prior to bending them into shape. This process was tedious at first but became much more streamlined after building the first few baskets. A consistent orientation of clips on each side of the baskets will expedite their attachment and removal from lines. Clips must be securely attached to lines or baskets will fall and hang from only one side. Over time, clips broke readily (both the clips on the baskets and the clips that secure lines to PVC support posts). Bringing an extra supply of clips along is recommended when working with this equipment type in order to save time. Based on the experience of the HPLDF, baskets should not be placed immediately adjacent to a PVC support post. A minimum of 10 inches should be left between the basket and support post to keep the basket from chaffing the PVC, and to allow space for a worker's hand to grab the line in order to move it to a higher position for desiccation. Moving the lines to a higher position requires two able-bodied individuals, but everyday operation of the system (collecting and deploying baskets) can be undertaken by one person.

### **Production Notes**

Oysters grown in the BST™ Crosshatch system were among the fastest growing in the 2016 season, but slowed over time. This may be due to the desiccation of the oysters, which reduced time spent in the water to feed. It is also possible that oysters in this system received additional jostling due to their position in the water column and weekly movement to a higher position, which may have chipped off new growth and resulted in reduced shell height. While growth in shell height was reduced over time, overall morphology of oysters grown in the BST™ Crosshatch system was generally favorable, according to the shape measurements used in this analysis. Worm infestation was significantly reduced in the BST™ Crosshatch system, with oysters grown in this system yielding the fewest worms of all systems employed.

# **BST™ Longline**

## **Installation and Operation Notes**

The BST™ Longline baskets attach to their line via two swivel clips along the top of the basket. Since these clips swivel into place (as opposed to fully latching with a closed hook), it is critical that the appropriate sized line is used with this system. Using a line that is too large or too small will result in baskets not attaching securely to the line, and coming loose from their lines. The monofilament/dripper tube line provided by BST is sized correctly for these baskets and should be utilized in their operation. The clips for this line appear to be sturdier than those used in the crosshatch orientation and did not break over time. This system can be operated by a single individual.

## **Production Notes**

In their first year of growth, oysters in the BST™ Longline system grew more slowly than other systems employed, but growth increased in the 2017 season. Their morphology was generally favorable compared to other systems employed. The condition index of oysters grown in the BST™ Longline system was significantly higher than that of oysters grown in the rack and bag system, indicating that the oysters in the BST™ Longline system have a greater meat yield than the rack and bag. They had more worms per oyster than the desiccated systems, which we believe to be a product of their subtidal exposure. A desiccated BST™ Longline oyster may have reduced worm infestation, but this cannot be determined at this time.

# **OysterGro®**

## **Installation and Operation Notes**

OysterGro® cages should be securely clipped to a longline using strong guy-lines and swordfish/longline clips on either side (Figure 12). Surface waves lead to pulling on the clips and lines and a reduced quality line will soon be recognized via an untethered cage. Guy-lines should be long enough to allow the cage to be flipped, but not excessively long. Cages should be spaced to avoid cages bumping into one another; this can be achieved with the help of appropriately sized guy-lines. If ice is a possibility in the winter months, it is recommended that oysters not remain in the floating OysterGro® cages. If sinking cages over the winter to avoid ice, caps should be removed to allow the pontoons to fill with water, but caps should then be replaced to prevent the pontoons filling with sediment. Submerged OysterGro® cages may sink into soft or muddy bottom, leading to difficulty in springtime retrieval. Conversely, OysterGro® cages on a harder bottom may have a tendency to flip, leaving the cage of oysters on the bottom instead of the pontoons. It is recommended that sunken OysterGro® cages be checked regularly to ensure proper orientation and operation. A single individual can achieve daily operation (removing and replacing bags of oysters by wading in the water), but two able-bodied individuals are required in order to flip a cage for desiccation, or to hoist a cage to a position where bags can be accessed from a vessel.

## Production Notes

In the 2016 season, oysters grown in the OysterGro® system were among the fastest growing, but grew slower than other systems in subsequent years. This may be due to the desiccation of the oysters, which reduced time spent in the water to feed. It is also possible that oysters in this system received additional jostling due to their position in the water column and weekly movement to a higher position, which may have chipped off new growth and resulted in reduced shell height. While growth in shell height was reduced compared to other systems, the OysterGro® resulted in the only significant interaction in terms of morphology (width index), yielding the most favorably shaped oyster. Further, worm presence was reduced in the OysterGro® oysters, but not as much as the oysters in the BST™ Crosshatch system, which experienced more desiccation.

## Rack and Bag

### Installation and Operation Notes

Vexar® bags must be securely fastened to rebar racks using a marine-grade rubber tarp-strap and a fastener or hook designed for use in seawater. Small mesh bags (below 4 mm) are not recommended for use with the rack and bag system because they lack the rigidity required to stay in place on the racks. Appropriate tension must be applied to all four corners of each bag to ensure they remain in place and do not chafe along the racks. Racks should be examined periodically to ensure that welds are holding and that the racks have not become compromised. Water depth should be considered when placing a rack and bag system. Their operation requires the farmer to reach down and manually unhook the tarp straps in order to free the bags. If the water is too deep, the farmer may be required to dive, which can be unpleasant and inefficient at commercial scale. Intertidal or shallow areas are better suited to this system than deeper areas, but winter low tides and ice must be considered. This system can be operated by a single individual.

### Production Notes

Oysters grown in the rack and bag system consistently yielded fast growth and ranked among systems with the most growth compared to other equipment types employed in this study. Shell shape was generally favorable according to the shape analyses conducted in this study. While growth was rapid for oysters in the rack and bag, their condition index was inferior to two other subtidal systems, the BST Longline, and the Seapa system. Additionally, oysters grown in this system had many worms per oyster, especially when compared with desiccated treatments. It is possible that in an area with greater tidal flux, oysters grown in the rack and bag system will experience enough daily desiccation to reduce worm infestation. However, that cannot be fully assessed at this time.

# Seapa™

## Installation and Operation Notes

Seapa™ baskets can be attached to a range of line sizes, including the manufacturer recommended monofilament/dripper tube as well as marine nylon lines. Clips along the top of each basket fully clasp onto the line, yielding a strong and secure tether to their line. It is important to utilize the retention clips recommended by Seapa in order to minimize chaffing on the line and on the top of the clip itself. The absence of the retention clips can lead to the top of the clips wearing down to a point where they may break free from the line. Basket construction is easier when the materials have been left in the sun to warm prior to shaping. Further, some found it simple to employ a piece of 2x4 wood to bend the baskets around to encourage them to take on a rounded shape. Preparation of the line requires threading the heavy monofilament line through the rubber dripper tube. The addition of WD-40 to the inside of the dripper tube prior to threading will ease the process.

## Production Notes

Oysters grown in the Seapa™ system grew less than other systems in the 2016 season, then rapidly in subsequent years, ending the growing period as the largest oysters on the farm. Their morphology was generally favorable, but they were found to have a significantly reduced shape when compared with oysters grown in the OysterGro® (Width Index analysis only). The condition index of oysters grown in the Seapa™ system was significantly higher than that of those grown in the rack and bag system, indicating that oysters grown in the Seapa™ system have a higher meat yield. As with other subtidal systems, oysters in the Seapa™ system had high worm infestation, but this is likely due to a lack of desiccation. Desiccated Seapa™ baskets may yield oysters with reduced worm presence but that cannot be assessed at this time. A single individual can operate the Seapa™ system.

## Caveats

**While not explicitly addressed here, for all systems, secure anchoring mechanisms are critical and should be assessed based on local site conditions, including fetch, wind, and current. It must be noted that site conditions can vary among seasons, so a quiescent summer should not lead one to assume that other seasons will also be calm. Notes on directions of exposure and seasonal conditions should be recorded and will be useful in planning a successful operation.**

Based on results of this analysis, there are positive and negative effects that accrue to each equipment type. Results are specific to this study site and in the years conducted. Other results may be found with spatial and temporal variation. Please contact the authors for additional discussion or with specific questions.



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# APPENDIX I

## Equipment Types and Abbreviations



### A. BST™ Crosshatch (BST#)

A tensioned Australian longline system where baskets are attached to two lines, like rungs on a ladder.



### B. BST™ Long Line (BSTLL)

A floating Australian longline system.



### C. OysterGro® (OG)

A flippable floating cage system housing four, six, or nine bags per cage.



### D. Rack and Bag (RB)

A subtidal method consisting of bags secured to rebar racks, held ~10 inches off the seafloor.



### E. Seapa™ (SE)

A floating Australian longline system.

# APPENDIX II

## Detailed Capital, Installation, and Production Costs for Horn Point Laboratory Demonstration Oyster Farm

**Table 7.** Capital items purchased for HPL demonstration oyster farm use allocated equally across production systems.

Item	#	Cost per unit*	Total Cost*
Sledgehammer	1	\$39.00	\$39.00
Buoys	20	\$5.00	\$100.00
Dive skins	2	\$30.00	\$60.00
Rubber Mallet	2	\$10.00	\$20.00
Power Washer	1	\$3,000.00	\$3,000.00
<b>Total</b>			<b>\$3,219.00</b>
<b>Total shared cost allocated to each system</b>			<b>\$643.80</b>

*\*2016 US Dollars*

**Table 8.** Capital, installation, and production cost for Seapa™ System.

<b>Capital &amp; Installation Costs</b>	<b>Item</b>	<b>Unit</b>	<b>#</b>	<b>\$ per</b>	<b>Total Cost</b>	
<b>Materials</b>						
	Pods - 15L, 12 mm	each	80	\$7.30	\$584	
	Pods - 15L, 6 mm	each	12	\$8.62	\$103	
	Pods - 15L, 3 mm	each	8	\$12.79	\$102	
	End caps - no door 12 mm - streamline 600	each	80	\$2.15	\$172	
	End caps - w/ door 12 mm - streamline 600	each	80	\$2.98	\$238	
	End caps - no door 6 mm - streamline 600	each	12	\$2.30	\$28	
	End caps - w/ door 6 mm - streamline 600	each	12	\$3.15	\$38	
	End caps - no door 3 mm - premium 600	each	8	\$4.30	\$34	
	Endcaps - w/ door 3 mm - premium 600	each	8	\$5.20	\$42	
	Flexi clip 20 mm	each	160	\$2.53	\$405	
	Clamp Bearing 11 mm Assembly	each	160	\$2.08	\$333	
	Buoys	each	40	\$5.00	\$200	
	Augers	each	4	\$35.00	\$140	
	Shared materials				\$644	
<b>Labor</b>						
	Line Installation	hour	7.5	\$15.00	\$113	
<b>Total Capital and Installation Costs</b>					<b>\$3,175</b>	
<b>Production Costs</b>	<b>Item</b>	<b>Unit</b>	<b>#</b>	<b>\$ per</b>	<b>Total Cost</b>	<b>Cost per oyster harvested</b>
<b>Seed Cost</b>						
		per 1000	6.4	\$13.50	\$86	\$0.046
<b>Labor</b>						
	Seed Deployment	hour	0.1	\$15.00	\$2	\$0.001
	Processing	Hour	55.7	\$15.00	\$836	\$0.448
	Maintenance	Hour	11.1	\$15.00	\$167	\$0.089
<b>Total Production Costs</b>					<b>\$1,090</b>	<b>\$0.59</b>

**Table 9.** Capital, installation, and production cost for Rack and Bag System.

<b>Capital &amp; Installation Costs</b>	<b>Item</b>	<b>Unit</b>	<b>#</b>	<b>\$ per</b>	<b>Total Cost</b>	
<b>Materials</b>						
	Racks	each	6	\$104.50	\$627	
	Bags 2 mm	each	8	\$6.00	\$48	
	Bags 4 mm	each	16	\$6.00	\$96	
	Bags 9 mm	each	32	\$6.00	\$192	
	Bags 12 mm	each	32	\$6.00	\$192	
	Rubber Tarp Straps	10 ct box	10	\$16.00	\$160	
	Shared Materials				\$644	
<b>Labor</b>						
	Basket Building		3.35	\$15.00	\$50	
<b>Total Capital and Installation Costs</b>					<b>\$2,009</b>	
<b>Production Costs</b>	<b>Item</b>	<b>Unit</b>	<b>#</b>	<b>\$ per</b>	<b>Total Cost</b>	<b>Cost per oyster harvested</b>
<b>Seed Cost</b>						
		per 1000	6.0	\$13.50	\$81	\$0.021
<b>Labor</b>						
	Seed Deployment	hour	0.1	\$15.00	\$2	\$0.000
	Processing	hour	32.4	\$15.00	\$486	\$0.127
	Maintenance	hour	0.3	\$15.00	\$5	\$0.001
<b>Total Production Costs</b>					<b>\$573</b>	<b>\$0.15</b>

**Table 10.** Capital, installation, and production cost for OysterGro® System.

<b>Capital &amp; Installation Costs</b>	<b>Item</b>	<b>Unit</b>	<b>#</b>	<b>\$ per</b>	<b>Total Cost</b>	
<b>Materials</b>						
	Cage	each	20	\$150.00	\$3,000	
	Bags	each	214	\$6.00	\$1,284	
	Line	1200 ft roll	1	\$113.50	\$114	
	Longline Clips	each	40	\$1.10	\$44	
	Heavy Nylon Ball	each	1	\$24.50	\$25	
	Freight Delivery	each	1	\$150.00	\$150	
	Shared Materials				\$644	
<b>Labor</b>						
	Line Installation	hour	42	\$15.00	\$630	
	Equipment Assembly		20	\$15.00	\$300	
<b>Total Capital and Installation Costs</b>					<b>\$6,190</b>	<b>\$309.49</b>
<b>Production Costs</b>	<b>Item</b>	<b>Unit</b>	<b>#</b>	<b>\$ per</b>	<b>Total Cost</b>	<b>Cost per oyster harvested</b>
<b>Seed Cost</b>						
		per 1000	36.0	\$13.50	\$486	\$0.034
<b>Labor</b>						
	Seed Deployment	hour	0.75	\$15.00	\$11	\$0.001
	Desiccation Labor	hour	40.8	\$15.00	\$612	\$0.042
	Processing	hour	233.75	\$15.00	\$3,506	\$0.242
	Maintenance	hour	6.1	\$15.00	\$92	\$0.006
<b>Total Production Costs</b>					<b>\$4,707</b>	<b>\$0.33</b>

**Table 11.** Capital, installation, and production cost for BST™ Longline System.

<b>Capital &amp; Installation Costs</b>	<b>Item</b>	<b>Unit</b>	<b>#</b>	<b>\$ per</b>	<b>Total Cost</b>	
<b>Materials</b>						
	12 mm baskets	each	34	\$13.41	\$456	
	6 mm baskets	each	10	\$14.56	\$146	
	Clips	3 per bag	100	\$0.98	\$98	
	Line	ft	40	\$1.72	\$68	
	Riser Posts	each	16	\$5.78	\$92	
	Riser Post Clips	each	48	\$0.69	\$33	
	Buoys	each	40	\$5.00	\$200	
	Augers	each	4	\$35.00	\$140	
	Shared materials				\$644	
<b>Labor</b>						
	Line & Pole Installation	hour	27.75	\$15.00	\$416	
	Basket Building		1	\$15.00	\$15	
<b>Total Capital and Installation Costs</b>					<b>\$2,308</b>	
<b>Production Costs</b>	<b>Item</b>	<b>Unit</b>	<b>#</b>	<b>\$ per</b>	<b>Total Cost</b>	<b>Cost per oyster harvested</b>
<b>Seed Cost</b>						
		per 1000	6.4	\$13.50	\$86	\$0.038
<b>Labor</b>						
	Seed Deployment	hour	0.1	\$15.00	\$2	\$0.001
	Processing	hour	39.25	\$15.00	\$589	\$0.257
	Maintenance	hour	6.1	\$15.00	\$92	\$0.040
<b>Total Production Costs</b>					<b>\$768</b>	<b>\$0.34</b>



**Table 12.** Capital, installation, and production cost for BST™ Crosshatch System.

<b>Capital &amp; Installation Costs</b>	<b>Item</b>	<b>Unit</b>	<b>#</b>	<b>\$ per</b>	<b>Total Cost</b>	
<b>Materials</b>						
	12 mm baskets	each	250	\$13.41	\$3,353	
	6 mm baskets	each	12	\$14.56	\$175	
	Clips	3 per bag	783	\$0.69	\$540	
	Pilings and Installation	each	40	\$300.00	\$12,000	
	Line	ft	293	\$1.72	\$503	
	Riser Posts	each	96	\$5.78	\$555	
	Riser Post Clips	each	288	\$0.69	\$199	
	Screws	100 ct box	10	\$18.49	\$185	
	Shared materials				\$644	
<b>Labor</b>						
	Line & Pole Installation	hour	136	\$15.00	\$2,040	
	Basket Building		17	\$16.00	\$272	
<b>Total Capital and Installation Costs</b>					<b>\$20,465</b>	
<b>Production Costs</b>	<b>Item</b>	<b>Unit</b>	<b>#</b>	<b>\$ per</b>	<b>Total Cost</b>	<b>Cost per oyster harvested</b>
<b>Seed Cost</b>						
		per 1000	40	\$13.50	\$540	\$0.029
<b>Labor</b>						
	Seed Deployment	hour	0.75	\$15.00	\$11	\$0.001
	Desiccation Labor	hour	117.75	\$15.00	\$1,766	\$0.094
	Processing	hour	300.5	\$15.00	\$4,508	\$0.239
	Maintenance	hour	7.6	\$15.00	\$114	\$0.006
<b>Total Production Costs</b>					<b>\$6,939</b>	<b>\$0.37</b>