UNIVERSITY OF MARYLAND EXTENSION

Oyster Aquaculture Production Systems

Growers have cultured oysters for thousands of years and used many methods to raise them. The methods are based on the technology, materials, species, environmental conditions, labor and other parameters available in the area where oysters are raised.

You don t make money raising oysters; you make money by selling them.

While there are many methods used to raise oysters, not all are profitable for Maryland growers. Profitable operation is the most important part of a successful aquaculture business. As a grower, you should make decisions based on sound business practices. Information, advice and training are available through University of Maryland Extension specialists. Workshops and seminars are held throughout the year on such topics as production systems, business management and seafood technology to provide the training necessary for industry growth and development. As with all businesses, growers need to determine production costs and assess potential to maximize profit.

This publication provides information on the principal methods of oyster production currently used in Maryland and an overview of others used elsewhere. We are not advocating one system over another but provide information about existing techniques. Our goal is to get you, as a grower, thinking about what would work best for your location, the markets you are targeting, and the type of oysters you will raise.

The production method you choose will affect other business decisions. One of the most important is deciding on the method(s) you will use to produce your oyster crop. In the Chesapeake region, the principal production method for over a century has been *bottom culture*, which mimics natural oyster reefs. However, growers have adopted other methods as they looked for ways to raise oysters faster, to minimize the effects of disease and to produce oysters with specific traits to meet the demands of particular markets. Every method has positive and negative points and you should consider these prior to choosing your growing method. Also, other areas and countries have developed methods of raising oysters that could merit trials in Maryland.

Many Factors will Influence the System You Choose to Raise Oysters

Before making a choice, investigate as many different systems as you can, keeping in mind the location of your farm, Some growers will let you visit their operation or you may be familiar with local farms already in production. Oyster farmers are often comfortable showing methods and equipment they use because they know that expanding production benefits the entire industry. As a longtime grower once said, “What makes my company profitable doesn’t show up in photos – it’s the management of the business that makes it successful.”

Your target markets will also determine the best methods of oyster production. Oysters produced specifically for the half-shell or raw bar trade are often *cultchless*. They are produced by setting larvae on small shell pieces rather than multiple animals on a single shell as is done for bottom leases. Single oysters are more susceptible to predation and must be protected by growing them in enclosures. These containers need regular cleaning to assure robust growth of the animals.

However, bottom-cultured oysters have been sold to raw bars for over a century and you should not dismiss this method. In some areas, raw bars have resisted oysters that are “too perfect” because they do not look like those that are familiar to local consumers. Consumer preference for oysters is very subjective and varies widely across the country. Clearly, there is no one ‘perfect’ oyster.

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Factors for you to consider in choosing culture methods and equipment for your business include:

- Local conditions;
- Laws and regulations;
- Species being cultured;
- Available materials and cost;
- Labor availability and cost; and
- Target markets

Maryland Growers have Used Bottom Culture for Decades

The Maryland legislature first encouraged bottom culture production in the One Acre Law of 1830. The law was modified several times, leading to the Haman Act of 1906, which allowed higher acreage leases in various areas. Changes to state laws in 2009 made bottom leases available again and allowed them in areas where they had been banned for decades.

Growers still produce oysters using grounds leased from the state. Some leases have been passed down in families for generations, though many were inactive for years. Maryland's new laws and regulations require that leased grounds remain active and growers must submit regular reports and rental payments for the leases to remain valid. Growers also must submit production plans with their applications that outline the proposed farm operation.

To understand bottom culture, you must know about the structure of a natural oyster reef. A successful bottom lease is managed like a natural oyster reef. These reefs have a base of shells from previous oysters that died and now have new living oysters attached. Oysters tend to spawn *synchronously*, with eggs and sperm from female and male oysters meeting in the water column to fertilize and become *larvae*.

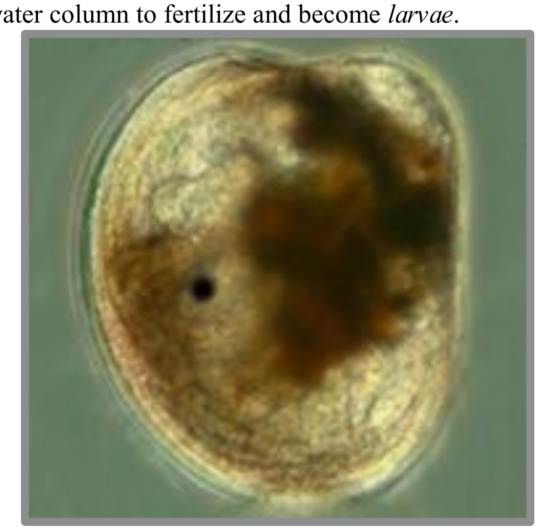

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Figure 1. Oyster larvae with 'eye spot' ready to proceed through metamorphosis

After fertilization, the resulting larvae exist in the water column for two to four weeks, depending on a variety of factors. During this time, they move in the water column (swim) using an organ called a *velum*. Movement is related to changes in water quality and other environmental conditions. The larvae then cease swimming and search for suitable substrate upon which to attach. If none are found, they can resume swimming to again be carried by the currents to different locations to complete their *metamorphosis* and become *spat* (Fig. 1).

One of the preferred places for larvae to attach is other oyster shells. Setting on these means that the resulting adult oysters will be concentrated in a reef, which greatly enhances the chance for successful fertilization when spawning occurs. Setting on other oysters also keeps the new animals from smothering in the bottom sediment. New oysters on existing shells form the "clumps" or mounds that are found on many reefs (Fig. 2).

Figure 2. The eastern oyster C. virginica

Oysters grow by filtering the water that flows past them, removing *phytoplankton* or small algae particles for food. As they grow and reproduce, more oysters are hopefully added to the community, building upon each other to form a reef structure.

Reefs provide many benefits for our bays. They are used as habitat by a variety of small plants and animals, many of which also help filter the water. This total *biofiltration* is beneficial for estuaries and helps cycle nutrients. Fish use the reefs to forage for food within organisms and at the bottom. Some fish use the reef structure for nesting.

In Traditional Production, Bottom-cultured Oysters are Grown Directly on Submerged Land Areas without Materials to Protect Them

In early years, growers leased areas classified as *barren*, or having few natural oysters on them. In most cases, these areas had sediment consisting mostly of mud or sand. Growers obtained oyster shell from processing plants and placed it on the lease area sufficiently thick to serve as a base above the sediment. Areas of buried fossil shell in the upper Chesapeake Bay dredged from historic oyster beds that were no longer productive provided another source for shell bases. These fossil shells were smaller than shucking plant shells but provided a reasonably priced alternative for growers to stabilize grounds for planting.

Operators waited for a "natural set" from larval oysters seeking a place to attach or purchased seed oysters from areas such as the James River in Virginia, a location with traditionally high reproductive success. The oysters grew and were harvested when they met legal size requirements.

When the Maryland oyster industry declined in the 1980s, many shucking plants were closed and the availability of whole shell became limited. In addition, concerns by some environmental groups over the dredging of fossil shell led to curtailment of that supply as well. Growers could have access to a cost-effective supply of shell if it became possible to reclaim it from defunct oyster reefs or previously planted locations. These options would minimize transportation costs, which are a large part of the initial cost of preparing bottom areas.

Shell is a critical factor in developing an oyster aquaculture industry.

Figure 3. Drag harrows are useful equipment for ground maintenance on submerged land leases. Photo: R. Bohn

Key to Stabilizing Bottom Culture Lease is to Keep Planted Seed Oysters or Naturally Setting Spat Out of Sediment so They Remain Healthy

If you want to attract natural spat sets, it is important to clean the cultch in early summer before the larvae are searching for places to attach. Renovating existing shell is a standard management tool for growers. This was traditionally done by towing an oyster dredge across the lease area, often with the bag removed. "Bagless dredging" involves raking the shell base to ensure that the currents carry away sediment and fouling organisms that have collected on the cultch. However, one study found less exposed shell after bagless dredging and other studies in recent years have documented that dredges often cause mortality in small oysters as well as spreading the important bottom substrate.

Other equipment, such as types of harrows (Fig. 3) are now used to clean cultch. Increased width and coverage makes harrows and other similar equipment more efficient compared to standard oyster dredges. Regardless of the type of equipment used, the user should operate so that tides and currents carry away sediment from the site. Sediment also should not settle back on other areas within the lease site.

Timing of this activity is also critical. During summer, which is when natural sets occur, exposed shell will quickly be covered by biofouling organisms which could have detrimental effects on spat settlement. Cultch renovation should, therefore, be timed just prior to when setting would occur.

Changes in Lease Laws Made it Possible for Growers to Obtain Bottom Culture Leases in Areas Formerly Classified as Natural Oyster Bars

Charted natural oyster bars were considered "off limits" to growers. However, oysters died in many of these areas and are covered with sediment to the point that they are no longer productive. The main advantage of the former natural oyster bar areas is that they have shell that growers could renovate and use productively for growing oysters. Growers can also add materials designed to support oyster seed deployed to the site.

The former oyster bars are now termed *Public Shellfish Fishery Areas* (PSFA) but oyster growers can petition to have the classification changed for leasing. Two key factors are used to decide if a PSFA can be leased: a) there must be no record of harvest in the area during the past three years, and b) there must be a population of oysters greater than one inch in size at a rate of one animal or less per square meter (approximately 15 bushels per acre).

Growers can renovate these areas with shell by dredging or towing other types of equipment, much like farmers till fields prior to planting crops. Some growers use crab dredges, which are wider and have longer teeth, making them more productive than the standard oyster dredge (Fig 4). In cases where shell does not exist or existing shell has silted over to where it would be too expensive to renovate, growers will have to plant new shell to develop the base required for successful aquaculture.

Producers could use other things, such as ocean clam shells to stabilize the bottom and provide a suitable amount and type of material for planting and growing oysters. This can be costly, however and should be carefully calculated before use.

Figure 4. Fouled shell at beginning of dredge cleaning.

Traditionally, Oyster Growers Obtained Shell from Shucking Plants

Chesapeake Bay oysters were “shucked” or had the meats removed and placed in cans or frozen in pouches for cooking. Oyster growers bought shell from shucking plants to build their bottom leases and attract spat to settle, but shells became scarce when the processing industry declined during the late 1980s.

Shell from shucking houses is referred to as “green” or “shucking house” shell. Processing plants stockpile discarded shells after removing the oyster meats (Fig. 5). These shells were traditionally moved each year in the spring for a variety of oyster repletion activities.

Shucking house operators can use the shells on their own leases, sell them to other leaseholders or to the State of Maryland. The State sets an annual price that they will pay per bushel. In 2018, the rate was $2 per bushel, while private sales were $5 or more.

Figure 5. Shell pile from a shucking plant stockpiled for aging before being used to set larvae for oyster seed.

Figure 6. Shell after dredge cleaning operation.

Whole shell is an important commodity for remote setting, a process for producing spat on shell for planting. Whole shell does not pack tightly when contained and provides space between them for water circulation when placed in setting tanks. This spacing is crucial for the microscopic oyster larvae to circulate between shells for distribution of the larvae while they seek locations to attach and begin growing. These *remote setting systems* are valuable tools in creating seed oysters for planting leases.

Remote setting has become a principal use for shell in recent years. Fresh oyster shell should be aged at least one year to allow bacteria and insects to decompose all organic material prior to using the shell in a setting tank (Fig. 6). Failure to use clean and sufficiently aged shell will cause severe mortality during setting. As your production increases, it will become more important to conserve and use shell for seed production.

Growers can obtain whole shell from other states, but they must have a permit from the Aquaculture and Industry Enhancement Division of the Maryland Department of Natural Resources prior to bringing it into the state. A grower must apply for a permit at least thirty (30) days in advance of when the shell is needed. However, the cost of transporting shell to a lease site is often very high. The most cost-effective methods move large amounts at a time, such as by barge or train, and minimize the number of times the shell is handled between initial location and final destination.

Deposits of fossil shells located throughout the Bay are the result of thousands of years of oysters living and dying. Many deposits are in the upper Chesapeake Bay and were used from 1960-90 for public oyster reef replenishment. The practice was discontinued due to opposition from environmental and recreational fishing groups.

If this source becomes available again, dredged shell is a useful base layer to develop a bottom lease. The shells are generally smaller and more brittle than whole or shucking house shell so they are not suitable for the current design of setting systems since they pack too tightly to allow the larvae to effectively circulate. While it would be possible to redesign a system to use them, their principal value lies in building the base on a bottom lease in order to plant seed oysters.

The price of dredged shell in the past was based on moving large volumes by tug and barge (Fig. 7). However, it was costly to transport the shell from upper Bay dredging sites to leases many miles away. The draft of the barges frequently was too deep to plant leases in less than six feet of water. Using smaller draft barges drove up the delivery price since transport prices were based on how much load could be moved for the cost of transportation.

Figure 7. Dredged shell was historically used for public oyster reefs and to stabilize bottom for leases

Ocean Clam Shells May Provide an Alternative for Building Bases on Leases

Large populations of ocean clams (surf clams and ocean quahogs) are harvested along the Atlantic coast. They are processed for a variety of food products and their shells are considered waste and sold for roadbeds and other purposes. These shells are large but more fragile than oyster shells so the pieces are too small to use in a setting tank for seed production.

However, clam shells can serve as an alternative for building the base on a lease. The key to using ocean clam shells is to accurately calculate the final cost of placing them on a lease and weighing their benefits against other choices of available cultch.

Clam shells may be available at plants from Virginia to New England. The shells must be trucked from often distant sources to an area near where the grower wants to use them. Fuel costs and labor for trucking are high, making inexpensive clam shells much more costly to use. Added to the transportation expense is the cost of transferring shells to a boat or barge for planting.

While ocean clam shells are mostly used to stabilize bottom, they also may provide suitable cultch for wild larvae to attach to once on the grounds. Because they are larger and less dense, tides and currents can shift and move clam shells.

Ocean clam shells can be used but cost may be a factor.

With Natural Shell from Shucking Plants and Dredged Shell Unavailable, Growers Tried Alternatives but Costs were Generally High

Experiments in recent decades evaluated everything from stabilized fly ash blocks from power plants, crushed plumbing fixtures and sections of demolished structures. These have not been biologically or economically successful when used for the commercial production of shellfish.

Restoration sites constructed of gravel or crushed construction materials were expensive but were justified because of the environmental benefits resulting from reef construction. Profit was not included as a metric for success in any economic analysis of construction materials.

Oyster grounds are constructed using stone and gravel, as well as ground material from roads, dams and bridges. The cost of these materials is generally high due to the expense of crushing rubble and moving it using heavy, expensive equipment. In addition, it is necessary to remove metals and other contaminants on some materials that could damage oysters and other bottom organisms.

The size of construction materials like stone can hinder dredging oysters for harvest. While material may pass screens of no more than four inches, the final product includes larger pieces that make it difficult to operate normal harvest equipment and requires methods such as the use of divers, to collect oysters from the lease area.

When the final cost of emplacing heavy stone and gravel are calculated, it rarely makes financial sense. However, with the current cost of shell, the cost all inputs should be calculated when making business decisions.

Manufactured Fabrics (Geotextiles) have been Investigated for Shellfish Aquaculture but are not Widely used for Oyster Production

Clam beds are routinely covered with plastic mesh nets to exclude predators (Fig. 8). There are many products that fall under the category of geotextiles, from woven materials used as sediment barriers surrounding construction projects to heavy mat-like ones used for roadbeds in marshy or unstable areas. Geotextiles may provide a way to develop smaller areas for oyster culture, although researchers need to fully explore the costs and environmental effects before making recommendations.

Figure 8. Geotextiles are currently used as predator exclusion nets to cover grounds in hard clam aquaculture

An experimental project conducted in Maryland used geotextile to cover a plot of sand. This bottom is normally not used for growing oysters because animals sink into it and die quickly. For the Maryland project, researchers laid out an area on sand using geotextile with a thin layer of oyster shell overlaying it. A control plot consisting only of a similar layer of shell on bottom sand was placed next to it. Hatchery spat on shell was placed on both areas but in less than a year, the control plot had completely disappeared while the treatment plot continued to provide habitat for several years afterward.

Geotextiles are available in large rolls but their use would require experimentation and proper permits. Divers would likely have to harvest the oysters since it would be difficult to use towed equipment on a base with geotextiles. They may be useful where oysters are not emplaced for harvest, such as in sanctuaries. However, permitting agencies' lack of experience with geotextiles in aquaculture applications would likely complicate obtaining permits for their use.

Geotextiles could potentially be used to stabilize areas for bottom culture.

Growers should Carefully Investigate if Innovative Aquaculture Methods Will Work for their Situation

All oyster-growing conditions are not the same. A grower who is interested in new gear or methods may want to consult with UMD Extension experts, other growers or conduct their own experiments before investing heavily in new methods or technologies.

Anything placed in bay waters will, over time, attract fouling organisms. Growers must keep gear clean so the meshes are open as fully as possible to maintain maximum water flow past the oysters. This allows them to reach their best growth rates but the labor to clean gear adds to input costs. The type and rate of fouling depends on where the gear is placed. Anti-fouling coatings could help reduce the labor and aid profitability of an oyster-growing business but these must be certified for use on food products and cannot contain toxins.

Watermen often treat crab pots with anti-fouling paints. Most of these paints, however, cannot be used on oyster equipment due to the chemicals that prevent fouling organisms from colonizing. Anti-fouling coatings are available that contain non-toxic substances that are suitable for use on oyster-growing equipment. Growers may want to evaluate the usefulness of these coatings at their site.

Ice floes moved by wind and tide can severely damage valuable structures and equipment. Shifting ice floes exert tremendous stresses on stationary items and have removed or destroyed docks, piers, aids to navigation and other structures. Extreme damage occurred during the winter of 1977, for example, when over three-quarters of the Chesapeake Bay froze (Fig. 9). Ice floes even caused the permanent tilting of an historic lighthouse.

High winds and abnormal tidal fluctuations can cause "blowout" tides, in which entire creeks may go dry. In winter, oysters will then be exposed to extremely low air temperatures which cause mortality from freezing. Surface ice can also descend onto oyster culture gear, crushing it and the animals contained in it. This occurred in February 2016 in several areas on the western side of the Chesapeake Bay. As a result, growers lost significant amounts of gear and shellfish.

Figure 9. Ice covering the Choptank River, Feb 1977

Surface Floats are Contained Culture Systems that Hold Oysters at the Top of the Water Column while Providing Protection from Predators

Surface floats are usually used for "cultchless" spat which is set on finely ground pieces of oyster shell rather than the "spat on shell" used in bottom culture. Cultchless spat are highly susceptible to predation from animals including crabs and rays and must therefore, be protected during their growing period.

<u>Among the variations in surface floats are:</u>

Taylor Float can be Used for Small-scale or Commercial Production

When used for oyster gardening, or small-scale production for ecological purposes, the Taylor float often has a suspended basket holding spat on shell. The float can also be used for commercial production using cultchless seed. Units are usually made from 4" I.D. schedule 40 PVC pipe with 90^o elbows at the corners to form a large rectangle or square (Fig. 10). Growers can modify the dimensions to fit their specifications, although 10 feet is normally the maximum length. Larger units become difficult to handle, especially for one person.

Figure 10. The Taylor Float holds oysters suspended from a PVC pipe collar and may be used in several different configurations

Taylor floats are simple to construct with materials available at home centers and plumbing supply stores. Prime and glue the collars so the piping remains watertight to maintain flotation of the units. Inject foam into the unit to prevent sinking in case a pipe or joint leaks. If a flotation collar leaks, one side may drop down, causing the oysters to fall into a large concentrated mass. In some cases, the entire unit can sink, which could potentially cause loss of oysters.

Several variations of the Taylor float exist depending on placement of the oysters. Some use a vinyl-coated wire basket suspended from the collar. For restoration oyster gardening, growers use spat on shell. For commercial culture, bags are placed in the baskets with the oysters periodically removed for cleaning and grading (Fig. 11). Maintaining this type of Taylor float can be challenging. The cages become fouled during the growing season, requiring growers to remove them from the water for drying, cleaning and maintenance.

Other versions place bags with cultchless seed inside the frame and simply secure them to the frame with large cable ties or elastic (bungee) cords. When fouling becomes heavy on the underside of the bags, the units are flipped and the fouling allowed to desiccate before being cleaned using brushes or power washers. Some growers have developed levers to fit over the floats to make it easier for a single person to turn them over. This is useful with larger 8- to 10-foot long versions which can become heavy.

Figure 11. Surface culture unit showing 3 of 6 oyster bags in growing area. Floats would be on top when in production while caps can be removed and the cage sunk in this configuration during icing or storms.

OysterGro® and Go Deep® Cage Systems were Developed in Canada where Winter Ice Normally Creates Problems

The OysterGro® and Go Deep® Cage systems consist of a vinyl-coated wire cage designed to hold plastic mesh culture bags. Specially designed molded floats are secured on one side of the units. When the units are in the water with the floats on top, the oysters are suspended beneath the surface to feed and grow. The floats are turned over for maintenance and cleaning so the cage rides on them which keeps the unit out of the water while the animals are cleaned and sorted. They are then replaced and the unit turned over for growth to resume.

Depending upon the size of the operation and available labor, growers may choose units that are equipped with different bag capacities, often holding up to six. The seed determines the bag mesh size. Using the largest mesh size possible allows maximum water flow through the bag for the best growth to occur while retaining the seed.

A unique feature of OysterGro® and Go Deep® Cage systems is the removable end caps that allow the flotation tubes to flood. When the cage is flipped so that it sits on top of the floats, the unit can be flooded and sunk. Growers normally do this to protect the units against ice damage or in anticipation of storm threats such as hurricanes.

After winter or storm threats pass, growers raise the units, remove water from the floats, and replace the end caps for oyster growth to resume. A vessel equipped with a winch is required to bring the sunken units to the surface. One problem with the OysterGro® and Go Deep® Cage systems however, is that when submerged on the mud bottom, the cages will settle into the hydrosoil. The floats can become filled with the soil, making recovery challenging and difficult for the operator to raise them again. It is generally better to replace the float caps once the units are flooded to prevent sediment from entering the tubes and making them heavy to lift and difficult to clean when retrieved.

Some Maryland growers are successfully using the OysterGro® and Go Deep® Cage systems (Fig. 12). Growers deploy the units by placing them on ground lines in strings of multiple units. Each cage has lines affixed to either side and they are attached to the main anchor line using longline clips. Main lines are moored using screw anchors large enough to provide the needed strength for prevailing weather conditions in the growing area. The anchors are often four to five feet long with surge buoys placed in the system to soften jolting on the moorings.

Figure 12. Float units are arrayed in lines on a water column lease for producing oysters in a high-energy environment

Bottom Cages have Become Popular in the Mid-Atlantic Region in Recent Years

Interest in bottom cages in the Chesapeake Bay region began when they were used during experiments to evaluate production of non-native oysters (Fig. 13). Companies in Maryland and Virginia now use them for commercial production and several local businesses manufacture bottom cages.

Figure 13. Bottom cages being used for production at the Hooper Island Oyster Aquaculture Company

Cages are available in a variety of sizes. Growers should choose units that are appropriate to the equipment available to service them. Larger units may be up to six feet in length and width while others are four feet square. Legs on the bottom keep the units raised from the sediment. The design allows growers to use the units on leases without a shell base, making preparation less costly. However, bottom cages have the same requirements as floats and growers must regularly tend them to keep them clean and free of biofouling that can reduce the amount of food available to the oysters. Labor required for continuous cleaning adds to the cost of production which affects profitability of the business. Normal stocking rates are 200,000 to 300,000 oysters per acre for bottom cages.

Growers usually use bottom cages to grow cultchless seed. Because single oysters are highly prone to predation, cages offer protection. Aside from losses from mortality, growers can harvest all live oysters. Cages can be placed using individual buoys or positioned on lines. The latter method cuts down on the number of buoys marking the growing area, making it more acceptable to local residents who may have the culture area within their view. Positioning cages on lines also makes it easier to find gear if it is tossed around during a storm. Where soft bottom exists, some growers insert PVC pipe into the legs of the bottom cages to provide more bearing surface to keep the units from sinking into the bottom, which makes them more difficult to retrieve.

Some growers have developed boats designed to service their cages. These vessels can be equipped with power washing pumps to clean the containers and with tables for culling and sorting oysters to place similar sized ones together. Some boats include rotating drums to tumble the animals and break off recent shell growth to spur them to develop better shape for raw bar markets, although severe or frequent tumbling can lead to higher mortality.

Rack and Bag is a Variation of Bottom Containment

Maryland oyster growers do not use rack and bag equipment because of the low fluctuation in tidal amplitude, which normally does not exceed two feet (Fig. 14). Rack and bag equipment usually is found where high tidal amplitude allows the racks to be out of the water at low tide, enabling growers to tend the gear.

Figure 14. Rack and bag system used for oyster production on intertidal flats in France. Photo: S.K. Allen, VIMS

System components include metal racks made of steel reinforcing bars bent and welded into platforms. Growers situate these platforms in growing areas and place plastic mesh bags with oysters on them during the growout cycle. The size of the mesh openings in the bag must be small enough to keep the oysters from falling through, which would cause them to be lost in the bottom. Oysters are moved to bags with larger mesh sizes as they grow to allow maximum water flow past them for growth.

Rack and bag systems minimize biofouling since the bags are out of the water during low tide, causing many fouling organisms to desiccate and die. This lowers labor costs for cleaning, but the investment in fabricating and installing racks can be high. Property owners often resist rack and bag systems because the gear is visible during low tide.

Rack and bag systems would likely do well on bottom areas with a high percentage of sand in the sediment. These very sandy areas are not good to grow oysters directly since the animals sink and die. However, it would provide bearing strength for field crews to walk the area and tend the crop. Growers can only use rack and bag systems where there is little chance of the oysters being exposed to freezing conditions when out of water in winter, which would cause high mortality. In most areas of Maryland, producers would have to move oysters to deeper water in the winter if they used rack and bag systems.

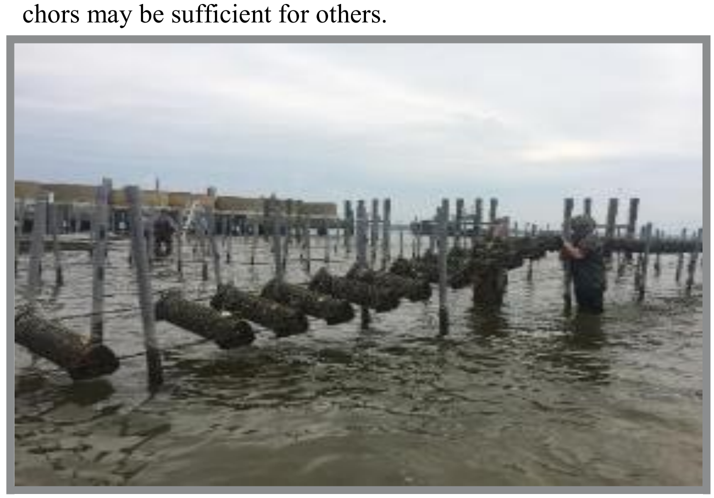
New Culture Systems have been Developed for Use in the Water Column

Several new culture systems were created in Australia. These have containers that hold oysters on lines where the units may be strung on ropes spaced with floats or placed crossways between cordage attached to poles at the ends. The units are sold in a variety of mesh sizes so seed can be moved to larger meshes as they grow to get maximum water flow to the oysters.

Australian Adjustable Longline Systems Gain Popularity in the Chesapeake, Particularly during Nursery Phase of Seed Growout

The Australian companies Seapa® and BST® developed gear for oysters using oblong baskets suspended from a longline (Fig. 15). The baskets are suspended from a tensioned line with PVC posts every three meters, or as required by environmental conditions. The posts include clips for raising and lowering the line. Bringing the baskets out of the water allows them to desiccate to control biofouling and oyster pests. The baskets are then lowered until the oysters are covered by water, allowing them to feed and grow. There are variations of the system which can be used where installation of tensioned lines is not allowed. In some areas, regulations, permitting issues or funding may prohibit installation of the pilings needed for longline systems.

Floating longline systems (Fig. 16) have baskets installed along an anchored longline with buoys placed between the baskets for flotation. The correct anchoring technique is determined after considering bottom soils, prevailing winds and tides and the potential for extreme weather. Some installations will need screw augers, while large weights used as anchors may be sufficient for others.



desiccation position at the Horn Point Oyster Demonstration Farm

BST® offers baskets in two mesh sizes (6mm and 12mm) that can hold 75-90 three-inch oysters. Seapa® offers baskets in four mesh sizes (3mm, 6mm, 12mm and 20mm). These come in 15-, 30- and 45-liter capacity with 15-liter baskets holding 75-90 three-inch oysters. To maximize flow through the baskets, install them perpendicular to the prevailing tidal current.

Figure 16. Seapa® longline baskets set up as a floating system.

Growers can arrange Seapa® and BST® baskets in a traditional longline orientation, with baskets hanging parallel from a single line. BST® components can be arrayed in a cross-hatch pattern with baskets attached perpendicular to two lines, like rungs on a ladder. This arrangement saves space and allows for 30% more oysters than other systems, possibly increasing output per acre. Contained-gear farms aim for 200,000 to 300,000 oysters per acre as their production target.

In the following sections, we describe several methods that would not be suitable for use in Maryland to provide you with information on the many variations and innovations used to culture oysters around the world. These are adapted to take advantage of labor, materials and conditions prevalent in those areas and highlight the ingenuity of oyster farmers.

Canadian and New England Growers Use Suspended Tray Stacks Since Water Shellfish Aquaculture Operations are Deeper than in the Chesapeake

The size of the seed determines the mesh size of suspended trays (Fig. 17). The trays are suspended on a center support pole that is attached to a high flotation buoy or floating platform which keeps the oysters in the water column for feeding.

Oysters are placed in a single layer in the trays, with each capable of holding 60 to 80 three-inch oysters. The trays allow the grower to use as much of the water column as possible, considering tidal amplitude and potential storm tide events. Trays should never rest on the sea floor but remain suspended, even at the lowest possible tidal point. Because the gear is quite heavy, growers will need power equipment such as a winch, to pull the stack from the water for grading, cleaning and sorting the oysters.

Shell Strings are Used on U.S. West Coast and in Asia

Figure 17. Stack units may be sized according to water depth.

In a shell string system, growers drill or punch holes in oyster shells which are placed on rope or wire. The strings are positioned horizontally across posts in the bottom or suspended from rafts. The strings give naturally occurring larvae a place to attach and become spat. In some instances, growers place the strings in setting tanks and add hatchery larvae so they can attach to the shells.

In the 1970s, researchers experimented with shell strings in Maryland. At one time, it was legal for leaseholders to place shell strings in seed areas to collect spat, although the practice was not readily adopted. Some growers tried horizontal shell strings in shallow areas with some success but the method was labor intensive and not widely used. After collecting the seed, shells were removed from the strings and placed on bottom leases for growout until the oysters were large enough for harvest and sale.

Problems with shell strings include acquisition of suitable amounts of whole shell, the labor and equipment required to place them on the strings, handling the gear once completed, and permits required to legally place them in off-bottom locations. Some foreign nations grow out oysters to market size with the strings remaining intact but that would require culture in depths that are not likely to be found in the Chesapeake or coastal bays.

Lantern Nets Vary Depending on Intended Production

Lantern nets, used primarily in Asia and Pacific islands, consist of circular rings covered with mesh netting in which oysters are placed. There are usually multiple nets placed on a vertical line and these are attached to horizontal growing lines and held up by large inflatable buoys to keep them near the surface. They are placed in areas that are considered acceptable to cultivate oysters. Growers must regularly maintain lantern nets because they have the same potential biofouling problems as other contained systems. Cleaning is periodically required and oysters must be graded by size before returning them for further growth or harvesting for sale.

Lantern nets are used in some areas to raise oysters for half-shell markets. The method usually requires water depths not available in Maryland. As with other contained culture systems, biofouling requires regular cleaning. Finding a site for an operation of this type would be difficult in Maryland and is unlikely to be profitable.

The pearl net is a variation on the lantern net. Pearl nets are a smaller version of the mesh cage and are usually stocked less densely than those producing food oysters. An irritant inserted by a highly trained specialist into the pearl oyster causes the animal to cover it with layers of nacre, creating a pearl. Nets are periodically serviced to control biofouling, manage the population and provide farm maintenance. The system grows animals from which pearls are extracted at maturity. However, the pearl-producing species is not native to this region and it is illegal to import and culture them.

Stick Culture is Used in Asia in Intertidal Areas with Mud Bottoms

Stick culture is rare in the Chesapeake Bay but is an example of the innovative methods used by growers around the world. The bottom used for stick culture is generally muddy and would not readily support the growth of oysters. Sticks are placed vertically to provide a location for natural larvae circulating in the area to attach and grow (Fig. 18). In some instances, the sticks are dipped in a light lime slurry attractive to larvae.

Figure 18. Asian stick culture raises oysters on mud bottom that would otherwise be unusable but would not be suited to Maryland conditions. Photo: S.K. Allen, VIMS

In his 1892 book *The Oyster*, Dr. William K. Brooks described ancient Roman oyster culture using bundles of sticks tied together and weighted with rocks to hold them near the bottom. The sticks would float and attract larvae. Growers would move the larvae-covered sticks to other areas for growth. Alternatively, the oysters grew in place until the increasing weight of their shells caused the sticks to drop to the bottom where the oysters would grow until harvested. Growers in some areas of the world still use the stick method, which illustrates the long history of ideas and methods used over the centuries.

As Industry Expands, Growers and Researchers Could Develop New, Potentially Successful Growing Methods

Growers interested in trying new ideas should develop well-designed plans to demonstrate the gear or method on a small scale before investing heavily in it. University of Maryland Extension specialists can help you develop your project and analyze results. The Maryland Department of Natural Resources Aquaculture and Industry Enhancement Unit will have to be consulted for potential permitting and they will likely arrange for a pre-application meeting with the Maryland Aquaculture Review Board for input by state and federal permitting authorities.

University of Maryland's Horn Point Lab has created a demonstration oyster farm near Cambridge on Maryland's Eastern Shore. It is operated as a commercial production facility to gather operational data on labor and related costs, carry out applied research into identified industry needs and conduct Extension educational programs.

DEFINITIONS

Bagless dredging	Use of an oyster dredge with the containment section consisting of a chain link and nylon mesh bag removed so it cultivates bottom without harvesting oysters.
Barren bottom	Areas of the bay containing one oyster per square meter or less; can be leased by growers and used to produce aquaculture oysters.
Bottom culture	Using bay bottom to place shell or other material, then deposit spat on shell to grow commercial oyster crops.
Cultchless	Oysters set on small shell chips; not actually without cultch but since fragments are so minute, it produces individual animals.
Geotextile	Permeable fabrics used to separate soil from other materials; often used in road and drain construction.
Green shell	Oyster shell that is not aged and may have substances such as oyster meat or other biological organisms remaining on it.
Larvae	Early life stage of the oyster prior to metamorphosis; a swimming stage between egg and spat.
Metamorphosis	Biological process involving a change in an oyster's life between swimming larva and sedentary spat.
Nacre	Organic-inorganic material deposited by a mollusk as a shell layer; makes up the oyster coating of a pearl.
Phytoplankton	Small single-celled plants that provide the principal oyster diet.
Public Shellfish Fishing Areas	Legally defined areas of the bay designated as reserved for commercial oyster fishing; may be modified by petition to the state management agency; if there has been no reported harvest for three years and the oyster population is one oyster per square meter or less, the area may be reclassified and leased.
Spat	Small oyster beginning post-metamorphosis when it has attached to a substrate and begins creating shell.
Substrate	The surface on which an organism lives; in oysters, it is the material at the bottom of an oyster reef which can be shell, rock or other material.
Synchronously	Events that occur in unison; at the same time.

CONVERSIONS FOR METRIC SIZES USED IN THIS TEXT

Length	Size	Volume
3 meters = 9.8 feet	3 mm = .12 inch	15 liters = 15.9 quarts
	6 mm = .24 inch	30 liters = 31.7 quarts
	12 mm = .47 inch	45 liters = 47.6 quarts
	20 mm = .78 inch	

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