Symposium on Alternative Substrate for Oysters

Report on the

Virtual Symposium

Feb 26–28, 2024

About the Symposium

Symposium and Report Sponsors and Organizers

This symposium and report were sponsored by the State of Maryland and convened and produced by University of Maryland Center for Environmental Science (UMCES). Lead organizers were Dr. Elizabeth North and Dr. Matthew Gray of UMCES Horn Point Laboratory. The symposium team also included David Nemazie, Conor Keitzer, Roshni Nair, Monica Fabra, and Kurt Florez. Graphic design and logistical support were provided by the UMCES Integration and Application Network (IAN).

For questions regarding this symposium and report please contact Elizabeth North at **enorth@umces.edu** or Matthew Gray at **mgray@umces.edu.** For more information, please see the symposium webpage: **https://www.umces.edu/alternative-substrate-for-oysters**

Please cite this symposium report as:

North, Elizabeth W., Monica Fabra, Conor Keitzer, Roshni Nair, and Matthew Gray. 2025. Symposium on Alternative Substrate for Oysters: Report on the Virtual Symposium Feb 26–28, 2024. University of Maryland Center for Environmental Science, Horn Point Laboratory. Cambridge, MD. 53 pp. *https://www.umces.edu/sites/default/files/SASSO-Report-2025.pdf*

Funding

Funding provided by the State of Maryland.

Acknowledgments

We thank speakers and audience members for their valuable contributions and Kurt Florez for assistance with IT during the symposium.

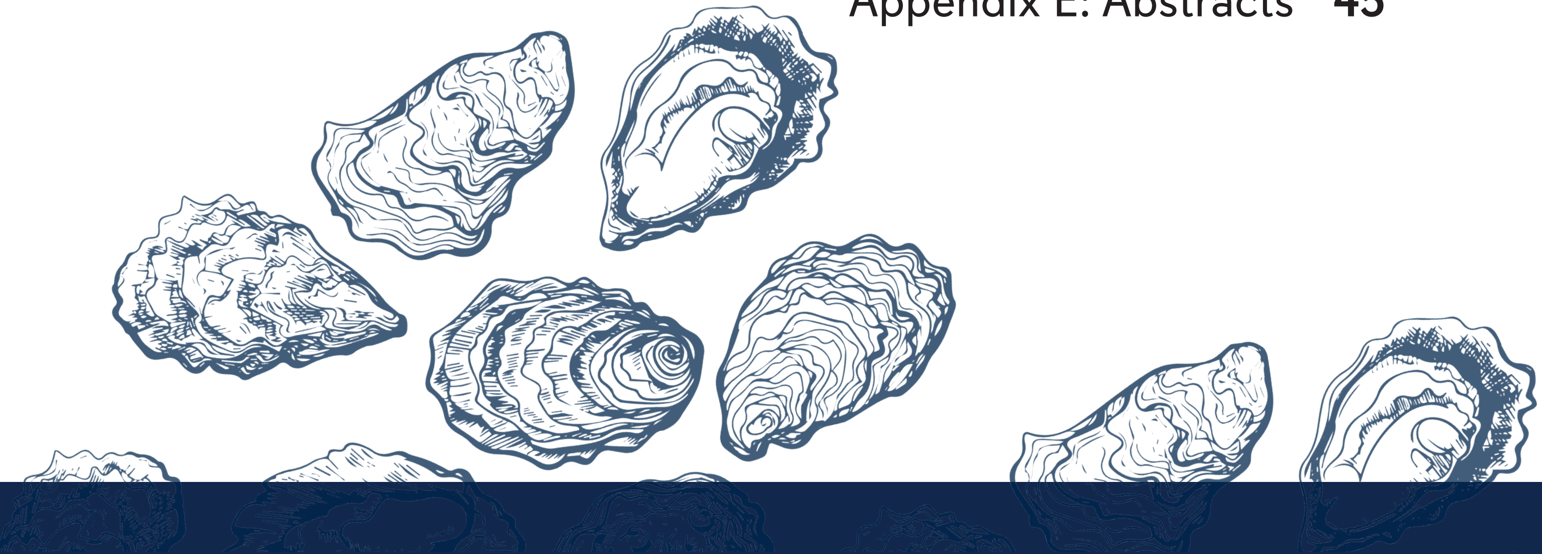
UMCES

100 YEARS OF SCIENCE

University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE

Scan here to access the symposium website

Table of Contents



Executive Summary

The Symposium on Alternative Substrates for Oysters brought together shellfish managers, fishermen, aquaculturists, restoration specialists, and scientists who shared and discussed their experiences and innovations on the use of alternative substrates for oysters. On each of the three days of the virtual symposium, at least 125 people from across the nation, Europe, and Canada attended. With 21 speakers from nine states, their collective knowledge brought to light numerous commonalities and offered new ideas and practices that will inform the use of alternative substrates in Maryland and beyond. While this Executive Summary highlights commonalities, innovative ideas, and knowledge gaps, the report itself offers a fuller account of each day's activities, with summaries of talks and discussions, tables of substrate types, and participant's input. Throughout this report, alternative substrate is defined as anything other than fresh shells of the Eastern oyster, *Crassostrea virginica*.

This symposium was part of a larger effort to inform the use of alternative substrates for oysters in Maryland. The demand for fresh shell of the Eastern oyster in Maryland by the fishery, restoration, and aquaculture sectors is substantial—recently totaling greater than 200,000 bushels per year—and the fresh shell resource is limited. While there are ongoing efforts to keep shells in the state of Maryland, alternative materials are being used or considered for use, including shells (*e.g.*, clam, whelk, dredged or weathered oyster shell) and stones (*e.g.*, limestone, river rock, granite). This symposium was held to better understand how alternative substrates are applied outside of Maryland for fishery, restoration, and aquaculture practices in large, subtidal areas and to learn about the success and failures of these efforts. The Symposium organizers are grateful to the speakers and attendees who made this event such a success.

Based on presentations at the symposium, it is clear that there is longstanding, widespread, and successful use of alternative substrates for enhancing oyster fishery production and restoration in large, subtidal areas along the U.S. Eastern seaboard and Gulf coasts. In some states without access to fresh shells, alternative substrates are predominantly or exclusively used, such as **limestone marl** in North Carolina and Texas, and **river rock** in Texas. In addition, **crushed and cleaned (recycled) concrete** has been used successfully in Florida, Maryland, Texas, and Virginia. In Virginia, **granite chips** are used in oyster enhancement programs in addition to the rich supplies of both fresh and **dredged oyster shells** that are available in the state. Non-oyster shells, such as **clam** and **whelk** shells, are being successfully used as substrates in New Jersey.

The importance of the size of the substrate for different applications was a common theme at the symposium. Small sizes of stones (< 1 to 2 inches) are regularly used in harvest areas whereas larger stones are used in sanctuaries. Smaller stones were found to be more appropriate for harvest areas because they do not damage juvenile oysters or fishing gear. In sanctuaries, larger stones provide habitat and raise the height of the bed above the bottom to promote oyster growth and survival.

Several innovative ideas and technologies also were brought forward, including shell recycling using suction dredge boats. These boats have a shallow draft and are specially designed to pull up the top 2 inches of shell and sediment from an aquaculture lease. This technique provides an efficient and cost-effective way to recycle shells within leases, ensure good spat catch, and—importantly—eliminate the need to purchase shells or other substrates. By suction dredging in the wintertime, the shell has several months of drying time on land to remove fouling, which improves spat catch when the shell is deployed in early summer. Symposium co-chairs noted that dredging in wintertime may also help protect against the negative impacts of sediment on seagrass in regions where seagrass does not grow in winter.

Other innovative ideas focused on sanctuary siting and construction. In multiple states, sanctuaries are sited so that the spawning stock in a sanctuary is located so that water currents carry the spillover of oyster larvae out of the sanctuaries to harvest areas and thereby supplement the oyster industry. These large-scale coordinated programs for both sanctuaries and harvest areas are seen as a benefit that will ultimately enhance oyster populations and industry at the same time. In terms of sanctuary construction, innovative approaches for creating mounds tangential to currents (similar to maps of historic oyster reefs), using stone bases with shell tops, and using thousands of mini reef balls over large areas were also notable innovative approaches that show great potential. The recognition that concrete structures with high relief perform better than low-relief shell plantings in polluted regions can inform urban sanctuary restoration efforts.

In addition to the suction dredge described above, innovations in aquaculture focused on new materials and structures that have been developed and show success in nearshore regions. These innovations combine new ingredients into concrete making them more appropriate for oyster settlement and/or use new flexible materials that support oyster settlement and growth and create new shapes that have utility for nearshore and aquaculture implementations.

Measuring the success of alternative substrates was another topic of discussion at the symposium. Participants agreed that the metrics that are used to determine the success of alternative substrates need to depend on the objectives of the use of alternative substrates, which can differ between fisheries, restoration, and aquaculture. While **biological** performance metrics (larval settlement, spat growth and survival, biodiversity) are the most commonly used to assess the suitability of substrates, **structural** (size, rugosity, complexity, durability) and **economic** metrics (costs, availability, logistics) are important to assess.

Symposium participants identified several important knowledge gaps that need to be filled to enhance the use of alternative substrates. Material properties and scalability were unanimously identified in panel discussions as important topics that require greater investigation in each of the three sectors. The long-term performance of alternative substrates is a key gap—how long they last in the marine environment, how long they remain productive for oysters, and the cost-benefit of the different materials over the long term. Gaps in knowledge also exist around the use of novel substrates, especially regarding environmental impacts (*e.g.*, potential leaching of toxic chemicals and plastics) as well as how to scale up with them and transport them.

Issues that hinder the use of alternative substrates in Maryland also were identified. Public perception and acceptability, the supply and availability of substrates, and regulations and permitting for alternative substrates were highlighted. In addition, participants recognized the need in Maryland for equitable access and distribution of materials, more cost-effective deployment methods, and performance testing of alternative substrates including persistence in the natural environment.

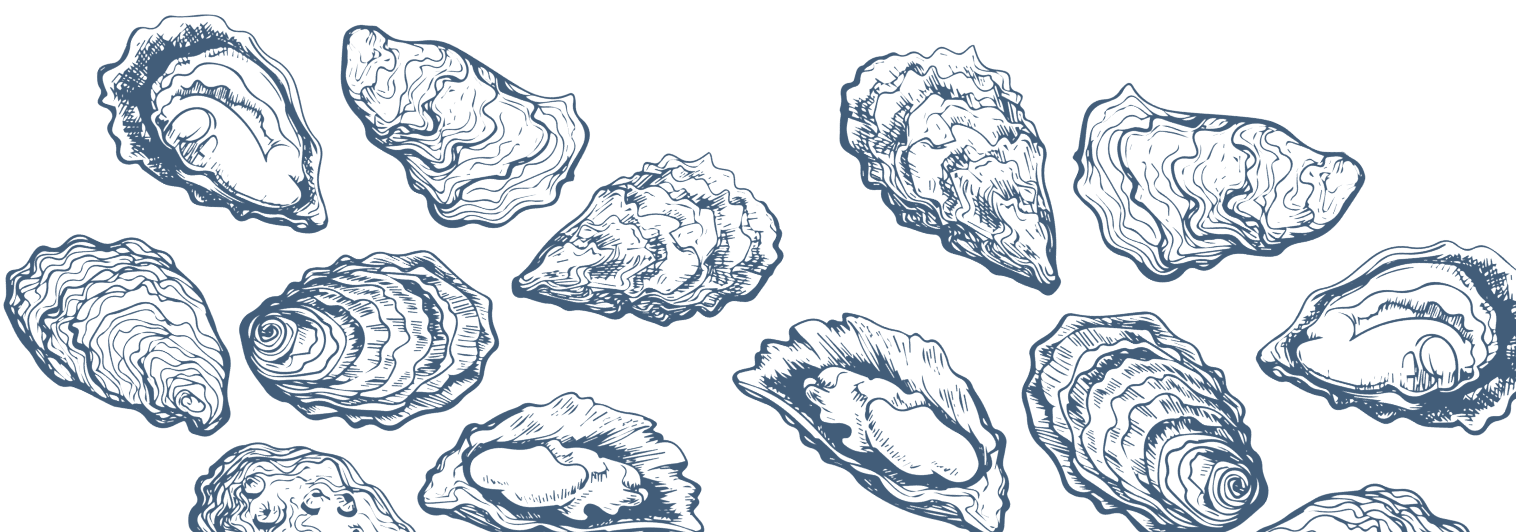
Looking forward, information from this symposium has many important uses, including offering new practices for enhancing fisheries production, restoration, and aquaculture in large subtidal areas as well as informing policy recommendations and guiding design of laboratory and field evaluations of alternative substrates.

Background

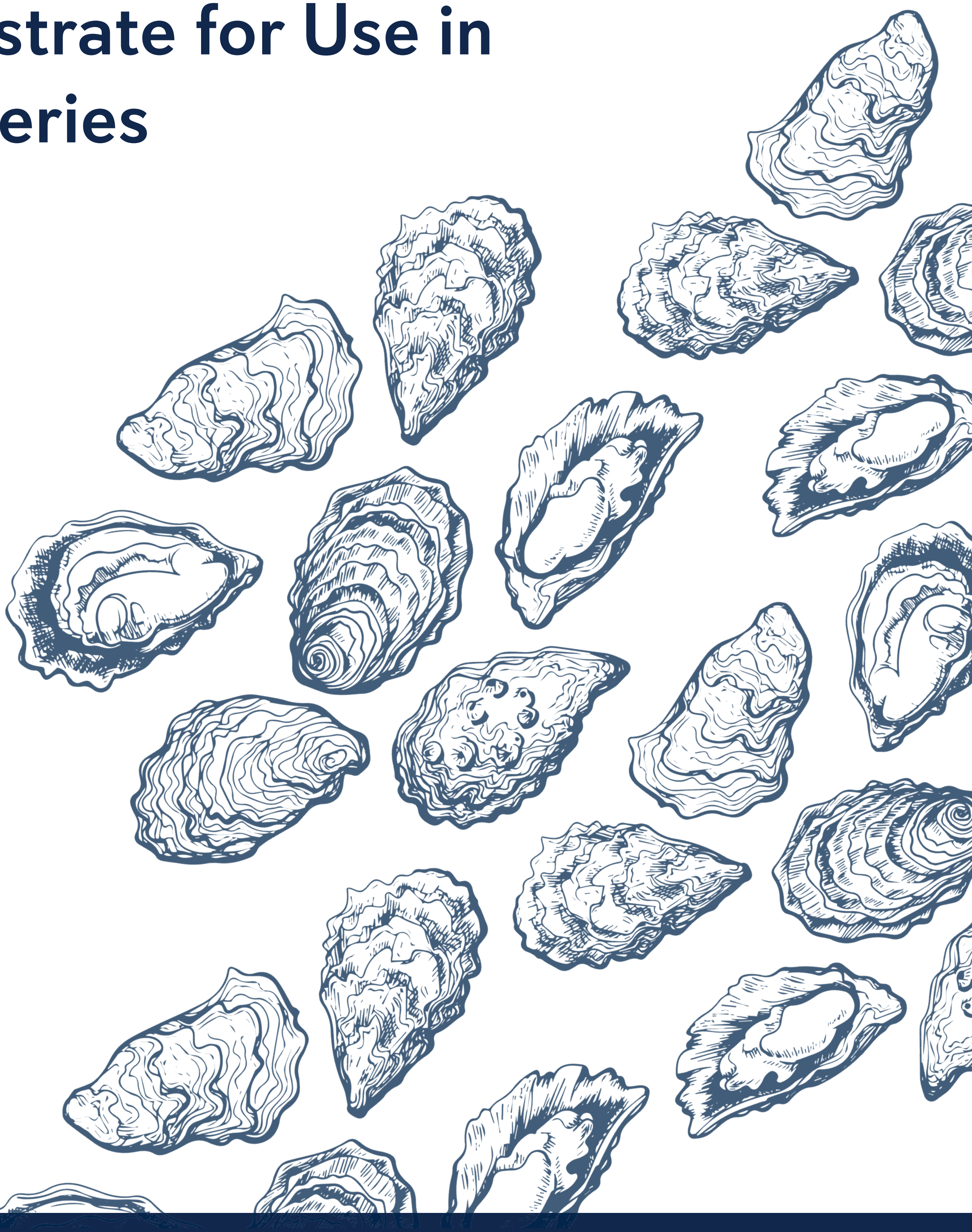
The Symposium on Alternative Substrate for Oysters (SASSO) was part of an effort to fill key knowledge gaps in support of Maryland's oyster resource and oyster industries. Chesapeake Bay is home to thriving commercial fishing and aquaculture industries and one of the largest oyster restoration efforts in North America. The lack of fresh shell substrate has become a major impediment to all of these activities and alternatives are being considered for large-scale use in restoration and industry efforts. To address this challenge, the Maryland General Assembly mandated a program (SB830 2023) that will evaluate:

1. Types of substrate, including fresh shell, fossilized shell, combinations of shell and alternative substrates that are most appropriate for use in oyster harvest areas.
2. Benefits, including habitat-related benefits, of using stones of various sizes in oyster restoration areas.
3. Alternative substrates used for oyster restoration or repletion in other regions, including the success of efforts to use alternative substrates.
4. Potential for retrofitting existing structures, such as riprap revetments that are unrelated to oyster restoration, but use materials similar to artificial reefs including oyster plantings.
5. Effect of spat size upon deployment on oyster abundance.

This symposium directly addressed Topic 3: to evaluate alternative substrates used for oyster restoration, or repletion, in other regions. The focus the SASSO symposium was on large areas and/or subtidal efforts with alternative substrates (*i.e.*, anything other than fresh oyster shell).



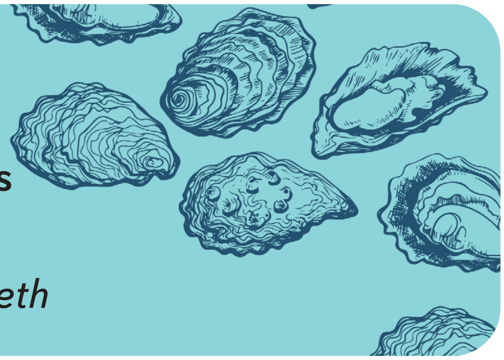
Day 1: Alternative Substrate for Use in Fisheries



Day 1: Talk Highlights

Day 1 of the symposium featured speakers from state agencies, academia, and non-governmental organizations who discussed using alternative substrates for oyster fisheries in large, subtidal areas. Maryland State Senator, Sarah Elfreth, who sponsored the legislation supporting the symposium, gave opening remarks. Senator Elfreth encouraged everyone to stay solution-oriented around the goal of restoring Maryland's oyster population and reminded us all that we are stewards of this important resource.

> **"....We all share a very similar goal, which is to restore the oyster population in Maryland and... ensure that the future generations of Marylanders can still rely on this keystone species."**
>
> *- Maryland Senator Sarah Elfreth*



Dr. Elizabeth North welcomed speakers and thanked them for sharing their valuable knowledge with symposium participants and the people in Maryland working to increase oysters.

Chris Judy

Director, Shellfish Division, Maryland Department of Natural Resources

Chris Judy gave a thorough overview of the different shell (dredged, surf clam) and non-shell (stone, concrete, slag) alternative substrates tested in Maryland to support local fisheries. Currently, the Maryland oyster fishery uses approximately 200,000 bushels of fresh shells per year but the need is easily for a million bushels per year. DNR used to manage a large-scale oyster shell dredging program that recovered 2 to 5 million bushels per year (1960–2006). The performance of dredged shells was quite good, with 2 to 50 times greater spat set on clean dredged shells than on natural oyster bars. Surf clam shells also were tested but were found to be brittle and too densely packed on the bottom. Recently, tests have been done with clam dredging boats that demonstrated that 1,000 bushels of shallow-buried oyster shells can be recovered per day and moved to nearby harvest sites. In past tests, spat were found to set on stone, concrete, and slag but the suitability of the material for fisheries is highly dependent on size, which needs to be small enough to be compatible with harvest gears. Also presented was the concept of man-made sources of alternate materials such as large-scale manufacturing of artificial shells similar in shape to actual shells. Any formula developed for man-made substrates would have to be thoroughly analyzed and deemed safe. Additional questions for man-made substrates include sourcing, weight, location of manufacturing, and policy issues of putting large amounts of man-made materials in the Chesapeake Bay.

Andrew Button

Virginia Marine Resource Commission

Andrew Button spoke about Virginia's approach to using alternative substrates to support fisheries in their waters that have consistent spat sets. Although they have found that oysters can set on any hard substrate, their program primarily uses dredged shells (500,000 to 700,000 bushels/year) and crushed stone (#57 stone chips, 1" or smaller). The stones need to be planted on a bit firmer bottom than shells to prevent sinking. He outlined their successful replenishment approach, which includes monitoring shell volumes and targeting 5 liters of substrate (fresh shell, dredged shell, or crushed stone) per m^2

as a minimum and 10 liters of substrate per m² as a goal to ensure reliable spat sets. A target 2-inch reef height works well and 250 tons per acre of crushed #57 stone will deliver this height at a new site that has a decent bottom. Less substrate is applied at sites that already have substrate. They use 2- to 4-inch size rocks in sanctuaries, which can be deployed using a high-pressure water cannon, but these sizes are too large for harvest areas because the interaction with the fishing gear can damage oysters.

Doug Munroe and Bennett Paradis

North Carolina Division of Marine Fisheries

Doug Munroe and Bennett Paradis discussed North Carolina's rehabilitation strategy, which includes a detailed site selection process, the deployment of artificial reefs, and a thorough monitoring program in both planting sites and oyster sanctuaries. Today they plant about 300,000 bushels of substrate per year. Although freshly recycled oyster shells are the preferred substrate, limestone marl has been used since 1981 and is now the primary substrate used in this program. It is local, relatively inexpensive, and the supply is reliable. In their decision-making process for site selection, they use a detailed GIS-based habitat suitability index, include fisherman/stakeholder input through annual surveys, and take into account the location of sanctuaries in an effort to create a network of reefs through the Sounds. Their monitoring program includes mapping clutch areas, assessing spat sets at sites < 3 years old, and tracking adult abundance on mechanical harvest areas to guide the opening and closing of harvest areas.

William Rodney

Texas Parks and Wildlife Department

Bill Rodney described several projects conducted in Texas using crushed recycled concrete, river rock, and limestone in a variety of reef configurations. Since 2007, over 600 acres of oyster reef have been restored in Galveston Bay using alternative substrates because they do not have a source of clean shells. Larger stones and concrete rubble (2–6") are used in no-harvest areas whereas smaller pieces (1–2") are used in harvest areas because the latter does not accumulate in dredges. Notably, fresh river rock placed near a natural oyster reef caught substantially more spat than the natural reef, indicating the preference of oyster larvae for clean substrate. While they have seen successful spat sets on all of the substrates, darker gray limestone is preferred by oyster leaseholders over white, chalky limestone which does not seem to last as long. Other novel substrates of opportunity (*e.g.*, granite countertop scraps, porcelain) need to be carefully examined for toxic effects (like leaching from plastics in countertops). Another issue is the cost of planting substrate at scale—it is too expensive to restore at the scale that needs to be achieved. Either cultch cost needs to come down or more funding needs to be obtained.

Sandra Brooke

Florida State University, Coastal Marine Lab

Sandra Brooke discussed restoration efforts in Apalachicola Bay (FL) following the loss of oysters and oyster reef habitat that culminated in a fishery closure in 2020. Recently, substrates of different sizes and types were compared in two restoration experiments. The first experiment showed that, while spat initially settled similarly on shell and limestone after 1.5 years, more market-sized oysters were found on large limestone rocks (5–7") than on small limestone rocks (2") or shell. The shell was dispersed by currents and did not form a lasting habitat in the shallow Bay. Although the large limestone rocks provide the most vertical relief and structural complexity, fishermen prefer smaller stones for better compatibility with the hand tong harvest gear (although hand tonging can be done over the larger limestone rocks). Data from the second experiment showed that after 6 months, there was no difference in abundance of spat, seed, or market-sized oysters between treatments with limestone rocks (5–7”), crushed concrete (4–6”), limestone rocks (5–7”) plus shell on top, or crushed concrete (4–6”) plus shell on top, but oysters were significantly smaller in the limestone rock only treatment. Monitoring is ongoing and an additional study is underway.

Kathy Sweezey

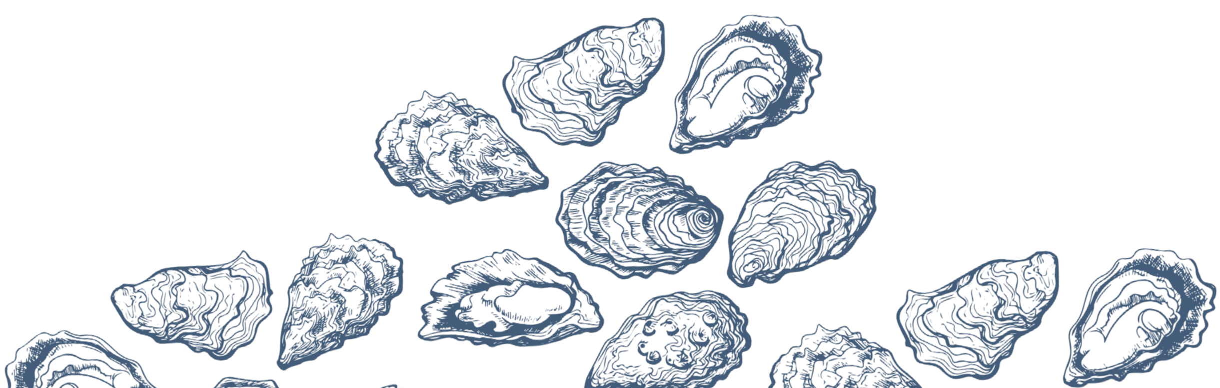
The Nature Conservancy in Texas

Kathy Sweezey talked about large-scale subtidal restoration efforts conducted by The Nature Conservancy (TNC), totaling over 150 acres across the Texas coast. In recent projects, limestone rocks were deployed to build artificial reefs in both sanctuaries and harvestable areas, with different sizes of stones in harvest areas (small rocks 0.5–4”) compared to those in sanctuaries (rip-rap ranging in weight from 60–1500 lbs). Despite the initial rapid success, they encountered challenges, such as costs, substrate availability, and lack of multiple competitive bids. In terms of emerging alternative materials for use in large subtidal areas, they tried to work with contractors specializing in alternative materials, such as those that demolish bridges or use 3D printed materials but were hindered by cost (three times higher than limestone) and a mismatch in the timing for construction and when the products would be available. A recent TNC report on oysters in the Gulf of Mexico calls for managing oyster populations based on the multiple benefits of oysters so that both ecological benefits and the human economic benefit of harvest are realized. In addition, it cites the need to enhance collaboration to reach project goals within limited budgets and to think creatively to increase the scale and pace of projects.

Matt Pluta

ShoreRivers in Maryland

Matt Pluta described a field experiment performed in the Choptank River (MD) that compared oyster shells to seven different alternative substrates with different orientations (*e.g.*, cup side up or down). They created platforms that contained 12 1-foot squares that held the different substrate types. Three platforms were deployed at each of the three locations in the Choptank River for five months in 2021. All but one platform were recovered. After recovery, each of the 12 squares from each platform was photographed and spat were counted. Squares with oyster shells—either cup-side up or cup-side down—had the highest spat settlement (mean spat per tile was at least 2x higher on shell than on all other substrates). Spat were found in lower numbers on clam shell, cobblestone, granite rock, and the back side of cement pavers. The substrates that caught little to no spat were marble tiles, ceramic tiles, brick, and the topside of cement pavers. It was notable that spat were found on the underside of the plastic platforms that were deployed in the river, but larvae did not set on the substrates or platforms that were held in the lab.



Key Points:

Knowledge gaps

During the panel discussion, speakers were invited to discuss key knowledge gaps for using alternative substrates in large areas and subtidal regions. Multiple speakers agreed that the long-term performance of alternative substrates is a key gap: how long they last in the marine environment, how long they remain productive for oysters, and the cost-benefit of the different materials over the long term. Gaps in knowledge also exist around the use of novel substrates (*e.g.*, granite countertops, toilets), especially regarding environmental impacts (*e.g.*, potential leaching of toxic chemicals) as well as how to scale up with them and transport them. Because biofilm formation has been found to be important for larval settlement, a better understanding of biofilm formation and community structure on alternative substrates is warranted.

Public perception and regulatory hurdles

According to panelists, the most effective way to overcome public perception challenges and regulatory hurdles is through careful site selection and communication to increase public awareness. Site selection includes avoiding high-use areas as well as depths that have any chance of being, or perceived as being, a navigation hazard. Employing habitat suitability analysis, as well as accurate tests to ensure the safety of materials, can enhance site selection and public perception. Increasing local public awareness and stakeholder engagement also was identified as valuable and essential, including being proactive about notifying the public, especially fishing communities about changes to navigation maps. In addition, the use of interactive online maps can increase understanding of where sites have been placed and are proposed.

Key metrics

The following metrics were identified by the panelists as key for measuring the performance of alternative substrates and their suitability for harvest areas: oyster abundance by size class, spat recruitment, substrate volume, and durability, the ratio of black shells to brown shells as an indicator of cultch depletion on the reef's surface, and, the costs of the substrate, its transportation, and deployment. In addition, revisiting sites with a side scan sonar can help determine if hard substrate is still available. Another metric to track is the amount of substrate deployed compared to the amount of oysters produced. For example, in productive regions in Virginia, approximately two times the amount of substrate is needed to produce a given amount of oysters.

Overcoming barriers

In order to overcome barriers related to the introduction of new substrates, the panelists suggested that site selection is critical: it should be in a new place—not at a site that already has oysters—so that if the experimental site works, it would add to oyster populations. In the process of site selection, it is important to consider all the different possible conflicts (*e.g.*, interference with boat traffic, fishing gear) and create a plan that is tailored to achieve the specific goals of the effort (*e.g.*, harvesting, reef restoration). In addition, strong outreach is important through step-by-step communication and the inclusion of different stakeholders.

Environmental concerns and biosecurity issues

The need for strict and consistent monitoring of alternative materials, particularly recycled materials, was highlighted by the panelists as important in order to avoid the introduction of pests, diseases, or unwanted toxic materials that could compromise the success of the programs. In addition, anything that will be applied at scale needs to be considered from many angles and checked thoroughly. Recycled materials like crushed concrete may not work well at scale because of the variability between loads and hence the need to check every load.

Other questions and ideas

Through the discussion, questions and ideas for improving oyster management emerged. On the reef scale, a better understanding of the acoustic signature of reefs might help with larval recruitment and assessing ecosystem services. On the landscape scale, it would be helpful to know how close in proximity a sanctuary should be to nearby harvest reefs to have a positive impact on harvest through larval transport. To take advantage of larval transport that can enhance oyster populations, it would be useful to promote public understanding that having large-scale programs for both oyster restoration in sanctuaries and replenishment in harvest areas is ideal. Another open question is the minimum acreage necessary to re-establish self-sustaining oyster populations in both sanctuaries and harvest areas.

Participants' Input: Day 1

Symposium participants were asked to fill out an online anonymous poll. The poll respondents on Day 1 of the symposium worked in the following sectors: Restoration (86%), Aquaculture (40%), Fisheries (30%).

The shell substrates most commonly used by the poll's participants were clam shells (36%), whelk shells (28%), *C. virginica* fossil shells (27%), and *C. virginica* dredged shells (21%), while limestone marl (24%), crushed concrete (24%) and granite (22%) were the most popular alternative substrates. Numerous poll respondents never used alternative substrates (26%) or used others (22% concrete complex structures like reef balls and castles, scallops, bamboo, tomato stakes, crab pots, pallets).

Larval preference (65%), availability (47%), and costs (44%) were selected by the symposium's participants as the top 3 priority features of alternative substrates. According to the poll's respondents, alternative materials should also support biodiversity and should not have harmful effects on water quality (42%). Other additional characteristics of alternative substrates were highlighted as important: integration into seascape, ecological/habitat function and development of functioning ecosystems, substrate complexity, permitting.

Scalability (68%), material properties (62%), and environmental footprint (62%) were selected by the symposium's participants as the main knowledge gaps surrounding the use of alternative substrates. The following features were also identified as important aspects requiring greater attention: long-term environmental impact, hydrological effects, impact on other species, ecosystem services, food safety, permitting, and development of objective methods to measure the suitability of new substrates.

When the poll's respondents were asked to name any issues with alternative substrates that should be addressed specifically in Maryland, public perception, equitable access and distribution of materials, and lack of cost-effective deployment methods were selected as the main problems.

Please see Appendix B for poll graphics and more information.

Different sizes of limestone marl used in Texas. Photos courtesy of Kathy Sweezey.

Granite (#57 stone) that was planted on a harvest area in Virginia and shows natural oyster recruitment less than a year after planting. Photo courtesy of Andrew Button.

Day 1: Table of Alternative Substrate in Fisheries

Speaker	State	Sector	Substrate	Used Since	Metrics	Summary
Chris Judy	Maryland	Fishery	Dredged Shells	1960	Spat recruitment, shell budget	Successful
			Surf Clam Shells	1995	Larval settlement, durability	Unsuccessful
			Slag	1935-1978	Spat recruitment	Successful; but potential toxins not measured
			Concrete	2022 (Experiment)	Spat recruitment	Successful
			Stones			Successful
Andrew Button	Virginia	Fishery	Dredged shells	1935	Spat recruitment, shell volume	Successful
			Granite stone chips (#57, 1" or smaller)	2014	Spat recruitment, compatibility with harvesting gear	Successful
Doug Monroe/ Bennett Paradis	North Carolina	Fishery	Limestone marl (rock)	1980	Spat recruitment, shell volume, local availability, compatibility with harvesting gear	Successful
Bill Rodney	Texas	Fishery	Crushed concrete (1–6 in)	2009	Oyster density, total area of restored reef	Successful
			River rock (0.75–6 in)	2009	Oyster density, total area of restored reef	Successful
			Limestone rock (1–2 in)	2020	Oyster density, total area of restored reef	Successful
Sandra Brooke	Florida	Experiment	Fresh oyster shell	2015	Spat recruitment, oyster growth and survival	Unsuccessful because shells dispersed
			Limestone rocks (2 in, 5–7 in)	2017	Spat recruitment, structural complexity, oyster growth and survival, compatibility with hand tongs (esp. 2-in rocks)	Successful
			Crushed concrete (4–6 in)	2023	Spat recruitment, oyster growth, and survival	Successful

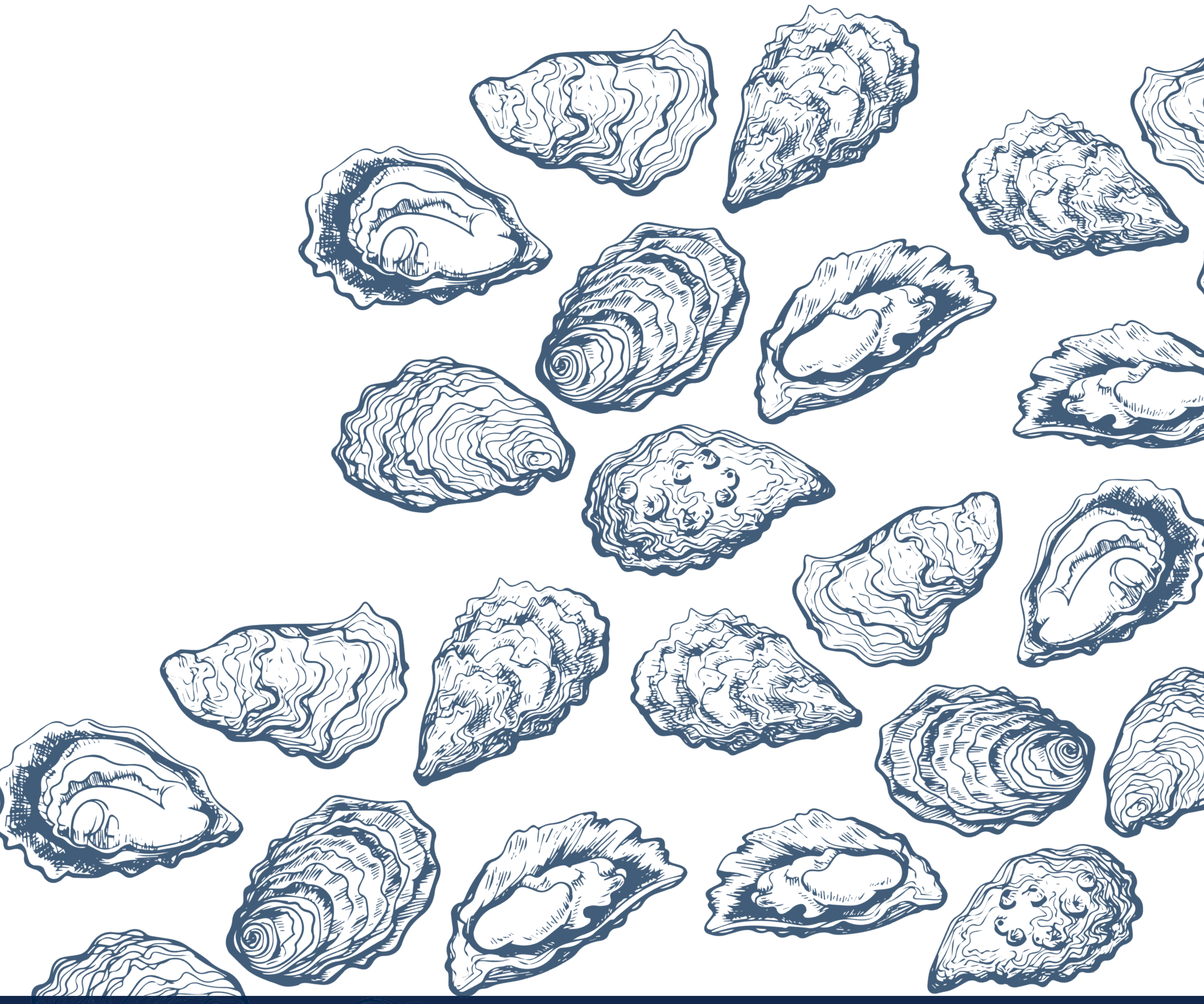
Table continued on next page →

Day 1: Table of Alternative Substrate in Fisheries

Speaker	State	Sector	Substrate	Used Since	Metrics	Summary
Kathy Sweezey	Texas	Restoration, Fishery	Limestone marl (harvest mounds: 0.5–4"; sanctuary rows: 60–1500 lb. pieces)	2014	Spat recruitment, survival	Successful; but issues with cost and supply
Matt Pluta	Maryland	Experiment	Fresh oyster shells	2021	Spat recruitment	Successful
			Clam shells			Successful
			Cement			Successful
			Cobble			Successful
			Granite			Successful
			Ceramic			Unsuccessful
			Marble			Unsuccessful
			Brick			Unsuccessful

Deployment of limestone marl in North Carolina. Photo courtesy of Doug Munroe.

Day 2: Alternative Substrate for Use in Restoration

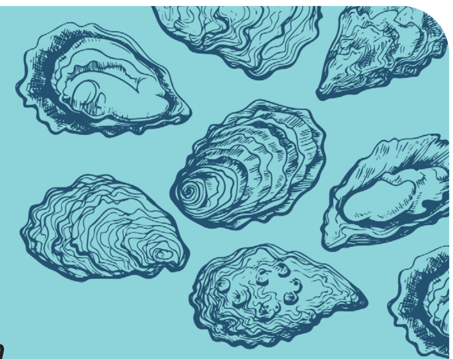


Day 2: Talk Highlights

Day Two was centered around using alternative substrates for oyster restoration and featured speakers from state and federal agencies, academia, and non-governmental organizations. Dr. Bill Dennison, interim president of the University of Maryland Center for Environmental Science (UMCES) and Vice President for Science Application, gave opening remarks. Beginning with the Native Americans that first lived in the Chesapeake Bay region, Dr. Dennison highlighted the importance of oysters to the people that lived there. Oysters continue to be a vital part of the social, economic, and ecological fabric of life in this region.

"...this conference is an exciting opportunity to share results, discuss ideas, and work collaboratively to enhance our understanding of nature, and employ science to create a better stewardship of our precious coastal resources."

- UMCES President Dr. Bill Dennison



Dr. Gray welcomed speakers and thanked them for sharing their valuable knowledge with symposium participants and the people in Maryland working to increase oysters.

Stephanie Reynolds Westby

NOAA Restoration Center

Stephanie Reynolds Westby opened the second day with an overview of the "Ten Tributaries" large-scale and multi-partners restoration initiative, based on the 2014 Chesapeake Bay Agreement, which has the goal to restore oysters and ensure their protection in 10 Chesapeake tributaries by 2025. To date, over 1,400 acres have been restored, with efforts completed in 9 of 11 tributaries. Alternative substrates, primarily stone of different sizes but also, in some cases, modular structures such as prefabricated cast concrete structures, were used in areas where there was no extant oyster reef (*i.e.*, where the reef needed to be created). For example, 1"–4" stones were used in the Manokin River on 31% of the 441 acres slated for restoration. In the Piankatank River, 2–4" stone plus VDOT A1 rip rap (approx. American football-size stones) were used on the 288 acres that needed amendment. Many projects involved multi-million dollar contracts for large barges of substrate that were deployed either by cranes or sprayed onto the riverbed with water cannons. The major barriers to the large-scale use of alternative substrates in oyster restoration in Maryland were public acceptance of the material, stakeholder use conflicts, cost of the materials, and the availability of materials.

Bennett Paradis

North Carolina Division of Marine Fisheries

Bennett Paradis presented their oyster sanctuary program in Pamlico Sound (NC) that started in 1996. Currently, the 15 large-scale oyster sanctuaries total 566 acres and range in size from 5 to 80 acres. They were established near oyster harvest areas to take advantage of larval spillover and provide a 'larval insurance policy' for the fishery. A range of materials have been used to build these sites, including marl limestone, granite, various forms of recycled concrete, reef balls, various shell types, and basalt, totaling over 240,000 tons of aggregate materials. After the initial sanctuaries were built in the late 90s, research suggested the importance of building up because relief on oyster reefs provides refuge from low dissolved oxygen events and creates better flow and food availability for oysters. Since 2003, NC oyster sanctuaries have been designed and constructed to be 4–6 ft high. Around 2017, managers began placing greater emphasis on building an interconnected and self-sustaining network of sanctuaries using a Habitat Suitability Model to guide site placement. The most recent projects (2017–current) have seen the construction of high-relief reefs created in ridges parallel to the bathymetry. Ongoing monitoring efforts via SCUBA surveys have resulted in a high-resolution, 6-year dataset quantifying oyster metrics on various alternative materials across Pamlico Sound. Results suggest that both total and adult oyster densities were significantly higher on granite and crushed concrete than on basalt, consolidated concrete, limestone marl, or reef balls. Additionally, there is a significant interaction between material type and material age, as oyster density declined at older sanctuaries (>25 years old).

Romuald Lipcius
Virginia Institute of Marine Science

Romuald Lipcius gave an overview of the lessons learned from subtidal oyster reef restoration in Virginia. In the Rappahannock River, large concrete structures had thousands of oysters per square meter of river bottom. In the Piankatank River (VA), a Habitat Suitability Model was used to guide restoration that resulted in many hundreds of oysters per square meter on reefs constructed with granite and shells. To build the Habitat Suitability Model, high-resolution side-scan sonar data was used to identify hard bottom areas. Next, a hydrodynamic and larval transport model was used to estimate larval dispersal and connectivity between sites to identify potential broodstock sites (that provide subsidies of larvae to the other reefs in the Piankatank), recipient sites (in a location to receive larvae but not contribute larvae to other reefs), and self-replenishment sites (that both release and receive larvae). Reefs were constructed in parallel ridges tangential to current flow as seen in historic oyster reef structures. Using precise habitat maps was important for avoiding bias in monitoring programs. The precision of abundance estimates can be improved by using a combination of both video camera footage and a subset of diver-collected samples.

Jay Lazar
NOAA Chesapeake Bay Office

Jay Lazar talked about a video-based assessment of habitat quality at restoration sites in Harris Creek (MD). The camera system allowed rapid assessment of 20 sites per hour with a three-person crew, resulting in 484 usable camera drops in eight sampling days. Results showed that reefs built with stone (6 to 12 inches in size) or with a base of stone had the highest mean habitat score followed by reefs constructed of mixed shell (oyster and clam or whelk shell) and then by seed-only (spat on oyster shell) reefs. Reefs with stone and mixed shells cost approximately the same and had high and consistent habitat scores whereas seed-only reefs were less expensive but resulted in more variable habitat scores. Overall, the camera system demonstrated that the alternative substrates worked extremely well and that the camera system was a useful tool for assessing habitat quality. It was noted that each sector (fishery, habitat restoration, aquaculture) likely has a different size of substrate that best suits their needs, with larger stone more beneficial for restoration efforts. Because larger stones can pose a challenge for traditional monitoring gears (*e.g.*, patent tongs), a camera-based system is useful for monitoring habitat quality at restoration sites.

Jennifer Zhu

Billion Oyster Project

Jennifer Zhu talked about the alternative materials and substrates used in New York Harbor through the Billion Oyster Project (BOP), which was established in 2014. BOP aims to restore 1 billion oysters to the Harbor and engage 1 million New Yorkers by 2035. New York Harbor is substrate-limited and larvae-limited, challenging oyster restoration efforts. To address the lack of suitable substrate, BOP established a shell recycling program, which now works with over 75 restaurants in New York City, to collect, cure, and reuse shells (primarily oysters, hard clams, and scallop shells). To contain shells and create bagged shell reefs or facilitate setting in its remote setting facility, BOP used coir bags (easy to use but not sturdy), biodegradable mesh bags (easy to use but may release microplastics), burlap bags (easy to use but degrades rapidly), or super trays (large capacity and easy to use but made of plastic). BOP considers oyster shells to be an ideal substrate for oyster larval settlement and incorporates recycled shells in project designs wherever possible: to create shell mounds, to serve as a setting substrate (spat-on-shell), or as aggregate in larger reef structures (such as reef balls). Some structures tested by BOP, such as piling wraps, proved more effective for enhancing habitat along shoreline infrastructure rather than restoring self-sustaining and functional oyster populations. Larger reef structures, such as reef balls, and eco-friendly concrete disks or blocks, demonstrate high larval setting rates and support high oyster density, but drawbacks related to accessibility, carbon footprint, biodegradability, scalability, and permitting require consideration.

David Schulte

US Army Corps of Engineers

David Schulte described results from a large-scale restoration project using reef balls in the Lynnhaven River in Virginia. The USACE, in partnership with the City of Virginia Beach, placed 28,045 1.5-ft-wide reef balls spaced 2.6 ft apart over an 8-acre footprint in subtidal waters. Mean oyster density on the reef ball network was found to be much higher than those noted on very successfully restored shell reefs in the Great Wicomico and Lynnhaven Rivers. Despite the reefs being less than three years old and holding only three-year classes, many adults exceeded 100 mm shell height, with the largest specimens being over 140 mm (5.5") long. Mean oyster biomass was 1,138 g dry weight per square meter of the bottom area covered by the reef ball network and exceeded the USACE goal by 3.5 fold and the Goal Implementation Team (GIT) goal by almost 23 fold. Gill net surveys indicate that the restoration site was an important foraging area and nursery to other species (*e.g.*, black sea bass, spot, seatrout), supporting benthic and pelagic biodiversity. A direct comparison between the reef balls and shell reefs in the Lynnhaven shows that the reef balls significantly outperformed shell reefs, suggesting that alternative reef structures should be seriously considered when planning large-scale oyster restoration efforts.

Russell Burke

Christopher Newport University

Russell Burke closed the second day of presentations with a description of a large-scale restoration project in the Elizabeth River (VA). They created five restoration sites, each with multiple types of substrate (shell beds, granite beds (6 to 12 inches in size), 2-ft-high pyramids, 2-ft-high reef balls, and 1.5-ft-high tables). Five years later, oysters were doing well at all sites but oyster abundances were not as high as those in the Lynn Haven River, likely because of poor water quality in the southern branch of the Elizabeth River. Mean oyster density exceeded restoration goals at all sites over all 5 years of monitoring, but mean oyster biomass was below restoration targets in all five years at 3 of the 4 sites with granite beds and 2 of the 4 sites with shell beds. All sites with pyramid and reef ball concrete structures exceeded mean oyster biomass thresholds in all years, potentially because they provided more height in the polluted waters. Notably, a side-by-side comparison of live oyster shell volume at four sites over five years showed that alternative substrate outperformed shell in 17 out of 20 comparisons. In polluted systems, alternative substrates enabled restoration goals to be met. Shell reefs were successful when built in areas with good water quality.

Key Points:

Knowledge gaps

A key aspect of the panel discussion on knowledge gaps for using alternative substrates in sanctuaries focused on identifying ecosystem services at both the reef and tributary levels with the recognition that these services can differ between regions and that some services are difficult to measure (*e.g.*, larval spillover and use by transient species). Another key knowledge gap was how to build sanctuaries spatially to take advantage of the combination of connectivity and habitat suitability, and, at the same time, be efficient and cost-effective (in terms of both material and transportation costs). Panelists pointed to the need to build sanctuaries to support the fishery and to get the most ecological "bang for the buck" with the limited funding and materials in hand. The ability to monitor sites where the substrate cannot be brought to the surface was also identified, as was the potential solution of using a camera and computer-assisted identification software. The question of how to marry restoration efforts in shallow water with shoreline protection efforts to best enhance coastal and climate resilience was identified as an important area in need of future work.

Public perception and regulatory hurdles

Persistence has helped with public perception and regulatory hurdles, and working with, and communicating with, affected communities. Listening and really taking into account what is being said in local communities is important—in other words, being sure to honor local public perception and trying to adapt. Some examples of responding to local communities include leaving wide buffers around navigational channels, not building in high-use places, trying alternative materials, and capping stone sites with shell or minimizing the use of alternative materials if shell is preferred. It is important to note that what sits well in the scientific community has not proven particularly compelling to those in the harvest community, so scientific measurements may not always be the right tool to inform public perceptions.

Key metrics

The following metrics were identified by the panelists as key to measuring/tracking the performance of alternative substrates and their suitability for use in restoration sites: oyster density (spat recruitment and survival), biodiversity and water filtration (ecosystem services), substrate volume, structural complexity and durability (*i.e.*, persistence over time), and indicators of reef health like biodiversity and the presence of species that do reef husbandry (*e.g.*, shrimp and mud crabs). Also, measuring the system's response to determine if a restoration effort creates conditions at a scale that allows the system to respond.

Overcoming barriers

According to the panelists, barriers to the large-scale use of alternative substrates for oyster restoration include costs, public perception, and "NIMBY" (Not In My Back Yard) resistance. There can be different amounts of resistance to restoration in some areas more than other areas. It's important to meet with local communities and politicians, demonstrate that you're listening to them, and give them a voice in project designs.

Environmental concerns and biosecurity issues

The need for thorough research on sources and compositions of alternative substrates was highlighted as crucial to avoid/reduce environmental concerns, especially when recycled materials are selected to be used in restoration programs (*e.g.*, avoid any concrete pipe that's been used in sewage systems). Other issues include being aware of the potential leaching of chemicals from recycled materials and the potential input of microplastics from biodegradable materials.

Other questions and ideas

In a system with poor larval supply, "sentinel reefs" (a network of smaller-scale reefs) could be used to test if the reefs are in locations that perform well before investing funds for large-scale projects. It also is important to take into account the observation that egg fertilization declines exponentially with distance away from spawners so highly concentrated broodstock on a small area may be more effective in producing larvae than the same amount of broodstock spread out over a larger area. Another important question in areas with low larval supply (*e.g.*, tributaries in upper Chesapeake Bay) is if large-scale efforts must be self-sustaining over the long term or do we need to recognize, and quantify, benefits that justify some maintenance costs (*e.g.*, overplanting spat-on-shell every 5 or 10 years) as worthwhile ongoing public investments.

Participants' Input: Day 2

Symposium participants were asked to fill out an online anonymous poll. The poll respondents on Day 2 of the symposium worked in the following sectors: Restoration (91%), Aquaculture (30%), Fisheries (16%).

The shell **substrates** most commonly used by the poll's participants were clam shells (46%) and *C. virginica* fossil shells (48%), while limestone marl (40%) and crushed concrete (34%) were the most popular non-shell alternative substrates. Numerous respondents used alternative substrates that were not listed in this question (42% river rocks, concrete complex structures (reef balls, castles, etc.), recycled concrete, other shells (scallops, flat oysters, mussels, cockles), bricks, tiles, bamboo, tomato stakes, crab pots, pallets, basalt, slate).

Larval preference (59%), support of biodiversity (53%), availability of materials (34%), and costs (32%) were selected by the poll respondents as alternative substrates' top **priority features**. According to the poll's participants, alternative materials should also promote high vertical relief, increasing the height of oysters above sediments (32%). The following additional characteristics of alternative substrates were highlighted as important: scalability and substrate complexity.

The **knowledge gaps** on the use of alternative substrates selected by the symposium's participants were the same as on the first day: scalability (80%), material properties (54%), and environmental footprint (63%). Ecosystem services, persistence of materials, and larval preferences also were identified as important aspects requiring greater attention.

When respondents were asked to name any issues with alternative substrates that should be addressed specifically **in Maryland**, the following barriers were mentioned: interaction/interference with SAV, use of recycled materials, permitting, public perception, lack of performance testing for alternative materials, lack of information on persistence of materials in the natural environment.

Please see Appendix C for poll graphics and more information.

C-dome deployed for oyster reef restoration in Virginia. Photo courtesy of Rom Lipcius.

Monitoring efforts include counting and measuring thousands of oysters at restoration sites in North Carolina. Photo courtesy of Bennett Paradis.

Day 2: Table of Alternative Substrate in Restoration

Speaker	State	Sector	Substrate	Used Since	Metrics	Summary
Stephanie Reynolds Westby	Maryland, Virginia	Restoration	Stones (small: 1–4”, large: 10–11”)	2011	Spat recruitment, biodiversity, structural complexity	Successful
			Prefabricated cast concrete structures	~2000	Spat recruitment, biodiversity, structural complexity	Successful
Bennett Paradis	North Carolina	Restoration	Mixed substrates: limestone, granite, shells, concrete, reef balls, basalt	1996	Spat recruitment, oyster growth, structural complexity	Successful (best performance: granite and concrete)
Romuald Lipcius	Virginia	Restoration	Concrete	NA	Spat recruitment	Successful
			Granite riprap (size: A1 class)	NA	Spat recruitment oyster growth	Successful
Jay Lazar	Maryland	Restoration	Stones (6–10 in) and crushed shells (whelk + clam)	2012	Spat recruitment, structural complexity	Successful
Jennifer Zhu	New York	Restoration	Coir bags	2020	Biodegradability, logistics, larval settlement	Unsuccessful
			Biodegradable mesh bags	2021	Biodegradability, logistics, larval settlement	Unsuccessful
			Burlap bags	2021	Biodegradability, logistics, larval settlement	Unsuccessful
			Piling wraps	2021	Spat recruitment, oyster growth, durability	Successful (enhancement technique)
			Reef Ball	2021	Spat recruitment, durability, carbon footprint	Successful
			ECOncrete disk	2018	Spat recruitment, logistics, carbon footprint	Successful

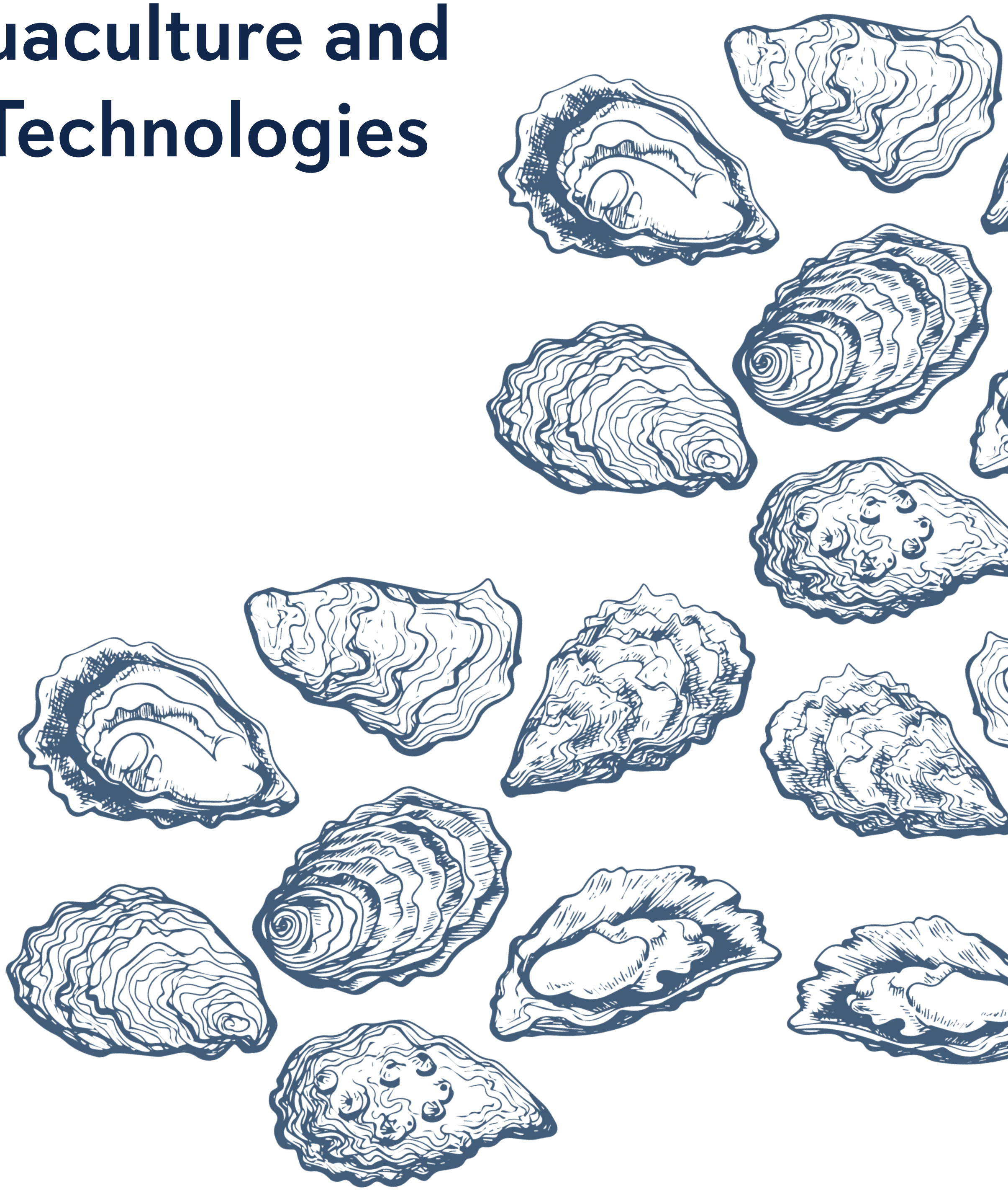
Table continued on next page

Day 2: Table of Alternative Substrate in Restoration

Speaker	State	Sector	Substrate	Used Since	Metrics	Summary
David Schulte	Virginia	Restoration	Concrete (reef balls)	2020	Spat recruitment, oyster performance (survival and growth)	Successful
Russell Burke	Virginia	Restoration	Shells + alternative substrates: granite stones (6–12 in), concrete (reef balls, table tops, pyramids)	2015	Spat recruitment, oyster performance (survival, growth, condition index), structural complexity (reef biomass and volume)	Successful

Pre-fabricated oyster reef installed in Baines Creek, Virginia. Photo courtesy of Russell Burke.

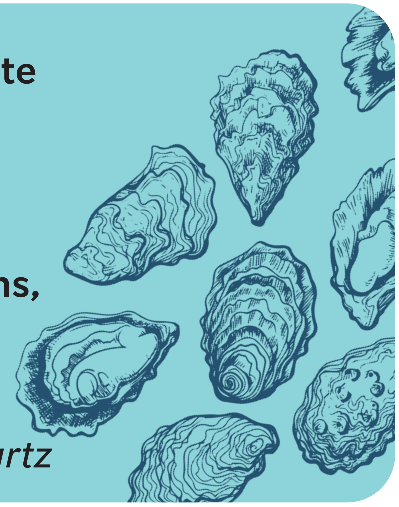
Day 3: Alternative Substrate for Use in Aquaculture and New Technologies



Day 3: Talk Highlights

Day three featured speakers from aquaculture, academia, and private businesses to discuss the use of alternative substrates in oyster aquaculture. Josh Kurtz, Secretary of the Maryland Department of Natural Resources, gave opening remarks. Secretary Kurtz emphasized Governor Moore's commitment to supporting the oyster industry and oyster restoration through the development of innovative solutions like alternative substrates.

> **"We know that we don't have enough shell and substrate or hard bottom in the Bay to support the industry, to support the sanctuaries, the restoration, as well as aquaculture....the work that you're doing to develop innovative solutions, and frankly, cost effective solutions, is going to be critical to us being able to expand aquaculture and restoration effort across the Bay."**
>
> *- Secretary Josh Kurtz*



Dr. North welcomed speakers and thanked them for sharing their valuable knowledge with symposium participants and the people in Maryland working to increase oysters.

Ward Slacum

Oyster Recovery Partnership

Ward Slacum began Day 3 with an overview of the findings of the Alternate Materials Workgroup of the Maryland Department of Natural Resources Aquaculture Coordinating Council. Workgroup members aimed to identify alternatives to shells that could be used in the remote setting process that involves setting hatchery-reared oyster larvae on shells, and then deploying the spat-on-shell at remote sites. He reiterated that oyster shell is an increasingly limited resource; it is in high demand and there is a national shortage. The workgroup decided that key metrics for evaluating alternative substrates for use in remote settings include suitability for oyster settlement and growth, cost and logistics, feasibility for use in large-scale efforts, where and how the material is currently being used, and regulations for use. The workgroup highlighted the current regulatory environment and the stakeholders' perception as major challenges for the use of alternative substrates. Key recommendations of the workgroup were to work with stakeholders from all oyster production sectors to communicate the benefits of alternative substrates; improve the regulatory environment for the use of alternative substrates, and determine and publish a list of approved alternative substrate materials and then test them for suitability in the remote setting process.

Steve Fleetwood

Bivalve Packing Company

Steve Fleetwood described the custom-built suction dredge boats that the Bivalve Packing Company uses to recycle oyster shells on their aquaculture leases in Connecticut and New Jersey. Their suction dredge boats were designed to be able to reach their leases and piers when fully loaded. Two boats are 105 ft long and 35 ft wide and the third is 90 ft long and 30 ft wide. The suction dredges only suck up what is loose on the bottom; it does not create holes on the bottom. With the smaller boat, 3,000 bushels of shell per day can be retrieved from the top 1 inch of the lease. The larger boats can recover

4,000 to 5,000 bushels per day. The shell can be unloaded in ~1.5 hrs with a skid steer loader or less than that if an excavator with clamshell bucket is used. Recovering shell is done in the wintertime, with the goal of being finished by the end of February in order to give the shell plenty of drying time on land so that fouling doesn't prevent spat catching when the shell is deployed in early summer. They use sophisticated electronics and dredge sampling to suction dredge with accuracy and caution to ensure what they do is compatible with the bottom type of each lease. Overall, suction dredging is an efficient and cost-effective way to recycle shells within leases, ensure good spat catch, and eliminate the need to purchase shell or other substrate.

Niels Lindquist

Sandbar Oyster Company Inc

Niels Lindquist presented a new plastic-free material for oyster habitat creation called the Oyster CatcherTM substrate (OCS)—a patented/patent-pending composite of cement-infused plant fiber cloths. OCS is now being used in North Carolina, Virginia, Georgia, Florida, and California. A variety of modular OCS shapes (*e.g.,* tables, pillows, mats, panels, patties) can be fabricated and combined in many different ways to create reef frameworks tailored to specific environments that facilitate oyster recruitment and reef growth, act as wave breaks and/or promote sediment capture. The relatively low OCS costs and ease of installation make it cost-effective for larger-scale habitat restoration and living shoreline projects in low- to high-energy environments and across hard to soft bottom types. Multiple projects now demonstrate OCS efficacy, for example, Lindquist and co-inventor/SANDBAR co-founder David Cessna, an NC commercial oysterman, are transforming intertidal sand flats into self-sustaining and rapidly expanding oyster reef-salt marsh mosaics. Another Oyster Catcher™ product, Tufts, are SANDBAR's pretzel-shaped oyster shell substitute. Tufts are ideal for achieving high set density in nature and remote setting, facile rearing of juvenile oysters, and ease of relay. Further, Tufts readily shed single spat as seed for aquaculture. Oyster Catcher™ substrates offer multiple means to create oyster-based habitats that provide diverse ecosystem services including shoreline protection, habitat provisioning, water-quality improvement, carbon sequestration and food.

Christine Thompson

Stockton University

Christine Thompson presented the results of two studies conducted in Southern Barnegat Bay (NJ), investigating the suitability of non-oyster shells as alternate substrates for remote settings. The first study involved two treatments: whelk shells set with oysters and transplanted oysters from a different river system. While oysters from both treatments thrived, the remote-set whelk shells had higher growth and less disease mortality than the transplanted oysters. An additional experiment was conducted in remote setting tanks to compare the preference of oyster larvae for oyster, whelk, and clam shell. Although there was variability between tanks and depths within tanks, the overall trend was the number of spat per shell was greatest for clam > oyster > whelk shell. After planting the shells in June 2019, the team conducted follow-up monitoring after 4 months to assess growth rates among the oysters on different shell types. Shell height was significantly greater on clam and oyster shell compared to whelk shell, but those that were on the whelk shell had higher survival. Overall, the remote setting process was highly variable and influenced by factors ranging from the larval batch, number of larvae, and environmental conditions in the setting tanks. Although there are tradeoffs in terms of which type of shell promotes the best oyster settlement or provides the best reef habitat, currently the choice of shell type is limited by what is available and cost-effective.

Mark Clark

University of Florida

Mark Clark described his group's development of Jute-Reinforced Calcium Sulfoaluminate (JR-CSA) for creating structures that promote oyster settlement and aid in coastal erosion protection and habitat restoration in low- to moderate-energy environments. CSA is primarily used for rapid infrastructure repair (runway, tunnel) where rapid set time and early strength development are required. Often called "green cement," CSA is a cement accelerator that has lower carbon dioxide emissions than ordinary portland cement. Oyster larvae were found to settle and grow on ceramic tiles coated with CSA in similar numbers compared to portland cement. When combined with jute, JR-CSA structures are plastic-free and can be constructed from readily available materials and deployed by volunteers with no specialized equipment. Currently, semi-pervious Jute Erosion Control Mats are used for structure instead of tight weave burlap because the loose weave reduces wave refraction by allowing wave energy to move into the structure and be absorbed. Numerous shapes can be created such as mounds ("reef turtles"), ribs, panels, and prisms. Empty prisms and panels weigh ~45 lbs and shell-filled prisms weigh ~120 lbs. JR-CSA materials have been deployed and are undergoing testing at 14 sites in Florida and one in South Carolina. While it is known that CSA mix composition and Jute quality are critical aspects of JR-CSA performance, material longevity, quality control mechanisms and optimal deployment configuration of reef panels and reef prisms are the leading knowledge gaps at this time.

Christopher Karwacki

C.J. Karwacki Consulting, LLC

Christopher Karwacki is focused on understanding the chemistry behind the oyster shells and using this knowledge to create alternative materials for oyster settlement. The main chemical components in the growth of an oyster shell are carbonic acid (CO_2 dissolved in water) and calcium hydroxide, which interact at the inside surface of an oyster shell to form an amorphous calcium carbonate phase. This phase eventually crystallizes, forming calcium carbonate crystals. Further strengthening occurs with the oyster's synthesis of acyl-acetylated chitosan (chitin), an organic binder that integrates with the crystalline structure, making it more resilient by adding stability through covalent and ionic bonding. This bonding sequence creates layers that repeat within the shell, forming a fortified, sequential structure that enhances durability. Materials like chitin are complex to synthesize, so they are using cellulose which can be effective and cost-efficient. They are developing layered structures using calcium carbonate encapsulated in cellulose or chitin, with the goal of building shell-like structures. These engineered materials could be used to form either small shell shapes or larger structures for reef environments. Controlled trials with the materials are ongoing.

Hunter Mathews

University of North Florida

Hunter Mathews is using Pervious Oyster Shell Habitat (POSH) for oyster reef habitat restoration along high-energy shorelines in northeast Florida. POSH structures are made with oyster shells and portland cement, providing structurally complex habitat. They use about half the cement of a comparable oyster ball and require a similar curing period on land of about a month before deployment. In one study, POSH-coated shells had higher oyster settlement than uncoated oyster shells. In a different study, when compared with oyster balls deployed in the same locations, POSH structures had higher oyster recruitment, better use by oysters of the surface area, and a more natural reef appearance after one year. Both types of structures had similar heights, sediment accretion on landward sides and scour on seaward sides, some gain in height from oysters, and similar shifting of the structures. POSH structures attracted higher densities of benthic organisms like mud crabs.

After two years, POSH structures continued to maintain greater oyster densities and use by benthic organisms, showing promise for restoration efforts in high-energy near-shore environments. A construction manual for creating POSH structures is available from University of North Florida.

Key Points:

Knowledge gaps

Panelists were invited to discuss key knowledge gaps for using alternative substrates for aquaculture in large areas and subtidal regions. Performance and handling of alternative substrates, in both remote setting and in-water applications, were identified as important knowledge gaps, as were the effect of substrates on harvest methods. Additional key gaps were related to the longevity and appearance of the substrate which, if fragmented, could end up as small pieces attached to oysters. Panelists questioned how small pieces of concrete would look on oysters intended for the half shell market and whether this would detract from the product or, if the concrete was colored, help with product tracing and enforcement.

Public perception and regulatory hurdles

One of the public perception challenges named by the panelists was concern over the safety of alternative materials. It was noted that subtidal practices were highlighted as more publicly accepted, compared to intertidal ones, because of their distance from the shoreline which makes them more invisible to local communities. For suction dredging, the large width of the suction dredge (6 feet) makes it look potentially damaging to the bottom, but actually the operators are quite careful; it only removes the upper 2 inches and creates no more disturbance than a half-foot dredge on the bottom. It was noted that public perception with shell piles on land can be negative if the smell and bird droppings (from birds attracted to the pile) are close to residential or commercial sites. These perception issues could be addressed through a collaborative approach between different stakeholders and better communication with the public.

Key metrics

Panelists identified several key metrics for alternative substrate, including setting efficiency, oyster growth, substrate durability of the material (how long it lasts), ease of harvesting, and knowledge of the spawning stock biomass in the system. Additional important metrics include weight of the material, return on investment, and the carbon footprint of the material and its transportation.

Overcoming barriers

Panelists discussed key barriers for use of alternative substrate including cost of the substrate and the fact that the regulatory environment is not conducive for using anything other than oyster shell. Additional logistical and timing issues related to substrate deployment were highlighted, as is the need for a labor force that could produce some alternative materials.

Environmental concerns and biosecurity issues

In terms of aquaculture, panelists discussed that alternative substrates need to be non-toxic and that biosecurity issues should be assessed for biological materials that come from out of the region.

Other questions and ideas

The idea of recycling shell with shallow-draft suction dredges on leases was discussed with interest, noting that there is a tremendous amount of shell already available in and on the Chesapeake Bay bottom that would not require deep dredging. It was also noted that suction dredges can be used to move large volumes of seed oysters and the process of removing fouling from the shell using suction is beneficial because even productive areas can end up with too much sediment in some years.

Participants’ Input: Day 3

Symposium participants were asked to fill out an online anonymous poll. The poll respondents on Day 3 of the symposium worked in the following sectors: Restoration (90%), Aquaculture (42%), Fisheries (29%).

The shell **substrates** most commonly used by the poll’s participants were clam shells (45%), whelk shells (35%), *C. virginica* fossil shells (42%), and *C. virginica* dredged shells (32%), while limestone marl (38%) and granite (32%) were the most popular stone alternative substrates. Poll’s respondents also used alternative substrates that were not listed in this question: recycled concrete, cement-coated jute, and foam glass.

Larval preference (54%), support of biodiversity (45%), availability of materials (45%), costs (42%), and durability (42%) were selected by the poll’s participants as alternative substrates’ top **priority features**. According to the poll’s respondents, the weight of alternative materials is also important because it needs to be light enough to be easily deployed, but also heavy enough to endure wave energy.

Scalability (73%), material properties (66%), and environmental footprint (56%) were selected by the symposium’s participants as the main **knowledge gaps** surrounding the use of alternative substrates. The ability to adapt to rising seawater levels was also highlighted as an important aspect requiring greater attention.

When the poll’s respondents were asked to name any issues with alternative substrates that should be addressed specifically **in Maryland**, public perception, stakeholder engagement, lack of performance testing for alternative materials, and lack of information on the persistence of materials in the natural environment were identified as major barriers.

Please see Appendix D for poll graphics and more information.

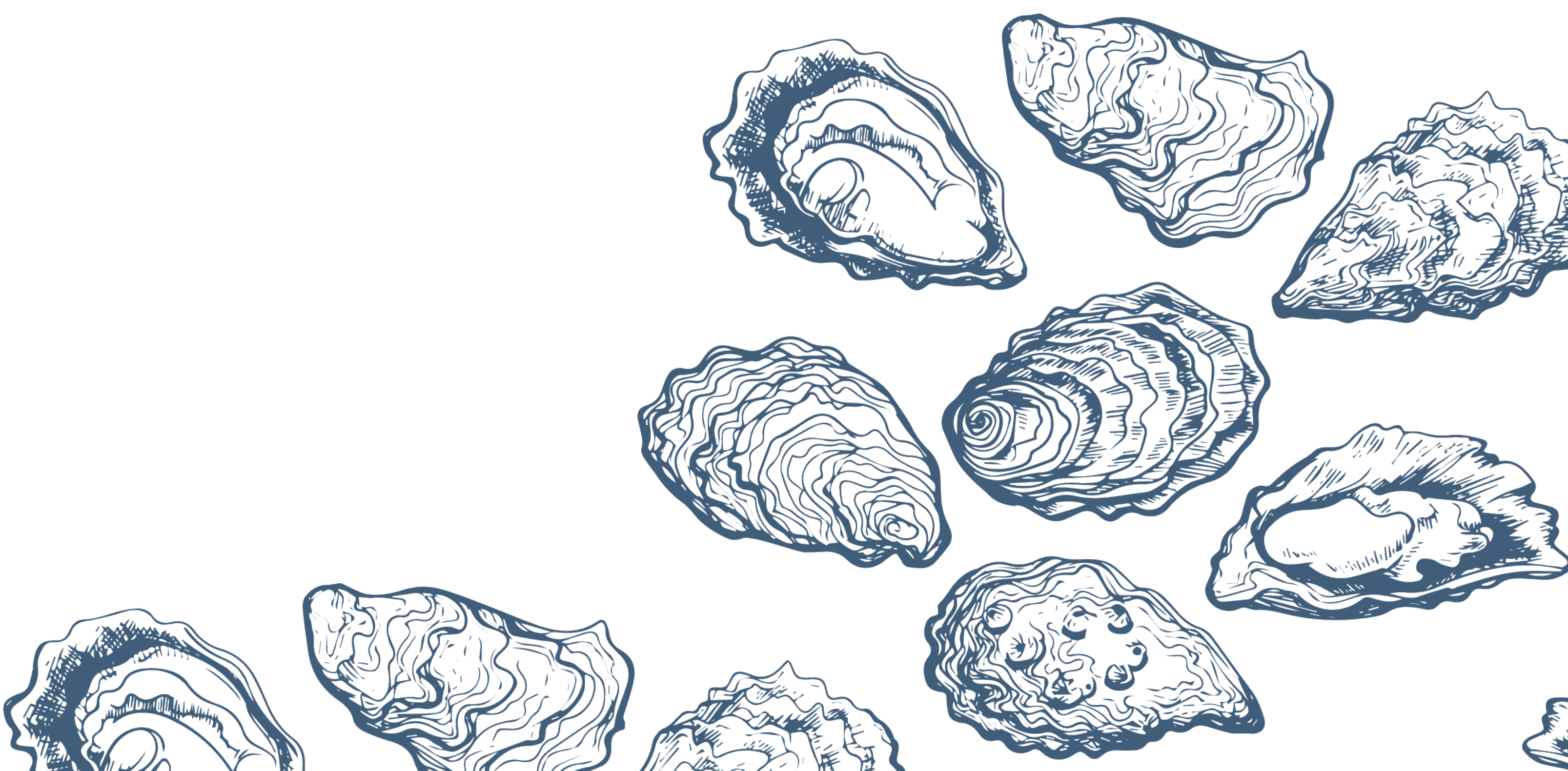
Suction dredge boat with a load of dredged shell in Delaware Bay. The head of the suction dredge is at the stern. Photo courtesy of Steve Fleetwood.

Oyster Catcher™ Tuffs used to catch wild oyster spat set in the intertidal and relay to aquaculture sites. Photos courtesy of Niels Lindquist.

Day 3: Table of Alternative Substrate in Aquaculture

<table>
<tr><th>Speaker</th><th>State</th><th>Sector</th><th>Substrate</th><th>Used Since</th><th>Metrics</th><th>Summary</th></tr>
<tr><td rowspan="3">Ward Slacum</td><td>Maryland, New Jersey, N. Carolina, S. Carolina</td><td rowspan="3">Restoration (sanctuaries), Aquaculture (remote setting)</td><td>Limestone marl</td><td>N/A</td><td rowspan="3">Larval settlement, spat growth, costs, logistics</td><td>Successful</td></tr>
<tr><td>Maryland, New Jersey, N. Carolina, S. Carolina</td><td>Concrete</td><td>N/A</td><td>Successful</td></tr>
<tr><td>New Jersey</td><td>Non-oyster shells (whelk, clams)</td><td>N/A</td><td>Successful</td></tr>
<tr><td>Niels Lindquist</td><td>North Carolina</td><td>Restoration, Aquaculture</td><td>Oyster Catcher™ (Cement: plant fiber)</td><td>2014</td><td>Larval settlement, spat recruitment and growth, cost, logistics, availability</td><td>Successful</td></tr>
<tr><td rowspan="2">Christine Thompson</td><td rowspan="2">New Jersey</td><td rowspan="2">Restoration (remote setting)</td><td>Whelk Shells</td><td>2016</td><td>Spat recruitment, survival and growth</td><td>Successful</td></tr>
<tr><td>Clam Shells</td><td>2019</td><td>Spat recruitment, survival and growth</td><td>Successful</td></tr>
<tr><td>Mark Clark</td><td>Florida</td><td>Restoration, Aquaculture</td><td>JR-CSA (Jute-Reinforced Calcium Sulfoaluminate)</td><td>N/A</td><td>Spat recruitment, biodiversity, costs, availability, logistics, environmental footprint</td><td>Successful</td></tr>
<tr><td rowspan="3">Hunter Mathews</td><td rowspan="3">Florida</td><td rowspan="3">Restoration, Aquaculture</td><td rowspan="3">POSH (cement + oyster shells)</td><td>2019</td><td>Logistics, costs, carbon footprint</td><td>Successful</td></tr>
<tr><td>2022 (experiment)</td><td>Larval settlement, spat recruitment and growth</td><td>Successful</td></tr>
<tr><td>2022 (experiment)</td><td>Biodiversity: fish and crustaceans</td><td>Successful</td></tr>
</table>

Appendix Table of Contents



Appendix A: Schedule of Events and Logistics

Monday, Feb 26: Alternative Substrate for Use in Fisheries

10:00	Introduction
10:05	Sarah Elfreth, Maryland State Senator
10:15	Chris Judy, Maryland Department of Natural Resources
10:30	Andrew Button, Virginia Marine Resource Commission
10:45	Doug Munroe, North Carolina's Division of Marine Fisheries
11:00	William Rodney, Texas Parks and Wildlife
11:15	Sandra Brooke, Florida State University Coastal and Marine Lab
11:30	Kathy Sweezey, The Nature Conservancy
11:45	Matt Pluta, ShoreRivers
12:00	Speaker Q&A
12:30	Chat n' Chew Breakouts
01:00	Plenary Discussion
02:00	Adjourn

Tuesday, Feb 27: Alternative Substrate in Large-Scale Restoration

10:00	Introduction
10:05	Dr. Bill Dennison, UMCES Interim President
10:15	Stephanie Reynolds Westby, NOAA Restoration Center
10:30	Bennett Paradis, North Carolina Division of Marine Fisheries
10:45	Romuald Lipcius, Virginia Institute of Marine Science
11:00	Jay Lazar, NOAA Chesapeake Bay Office
11:15	Jennifer Zhu, Billion Oyster Project
11:30	David Schulte, US Army Corps of Engineers
11:45	Russell Burke, Christopher Newport University
12:00	Speaker Q&A
12:30	Chat n' Chew Breakouts
01:00	Plenary Discussion
02:00	Adjourn

Appendix A: Schedule of Events and Logistics

Wednesday, Feb 28: Alternative Substrate in Aquaculture & New Technologies

10:00	Introduction
10:05	Josh Kurtz, Secretary, Maryland Department of Natural Resources
10:15	H. Ward Slacum, Oyster Recovery Partnership
10:30	Steve Fleetwood, Bivalve Packing Company
10:45	Niels Lindquist, Sandbar Oyster Company Inc.
11:00	Christine Thompson, Stockton University
11:15	Mark Clark, University of Florida
11:30	Christopher J. Karwacki, C.J. Karwacki Consulting, LLC.
11:45	Hunter Mathews, University of North Florida
12:00	Speaker Q&A
12:30	Chat n' Chew Breakouts
01:00	Plenary Discussion
02:00	Adjourn

Symposium Logistics

To join the symposium: Follow this Zoom link
http://tinyurl.com/5h44vwjf
Passcode: 104153

To ask the speakers a question: Type your question in the Zoom chat. Only the speakers will be able to see your questions.

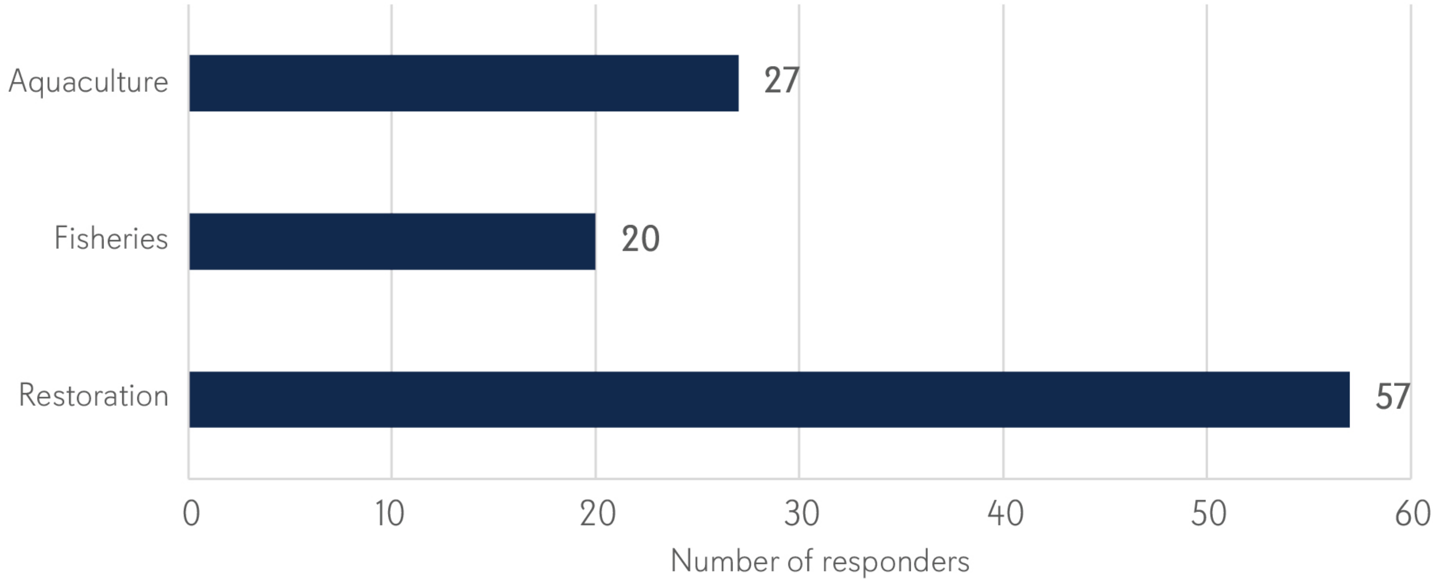
To join a Chat n' Chew: Follow the link provided in the Zoom chat at lunchtime.

To ask a question or make a comment during plenary: Type your question or comment in the Zoom chat. The moderators will be able to see your questions and comments and will relay them to the panelists.

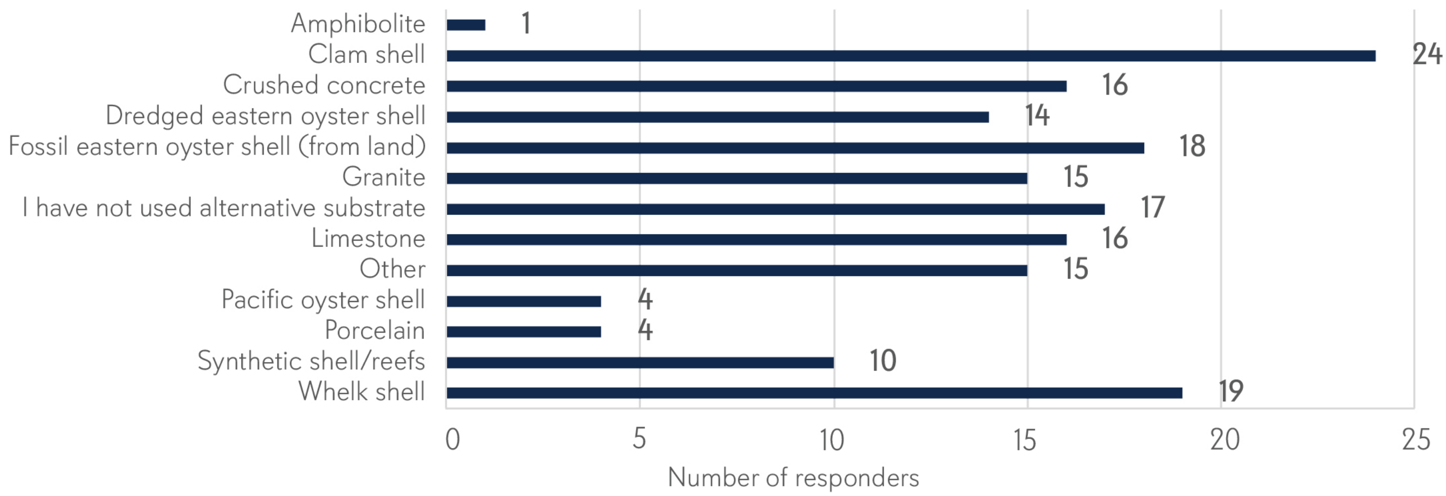
To receive a copy of the symposium report: All registrants will be sent the report.

Appendix B: Poll Results on Day 1

I work in the following sector(s):



What types of alternative substrates have you used? (check all that apply)

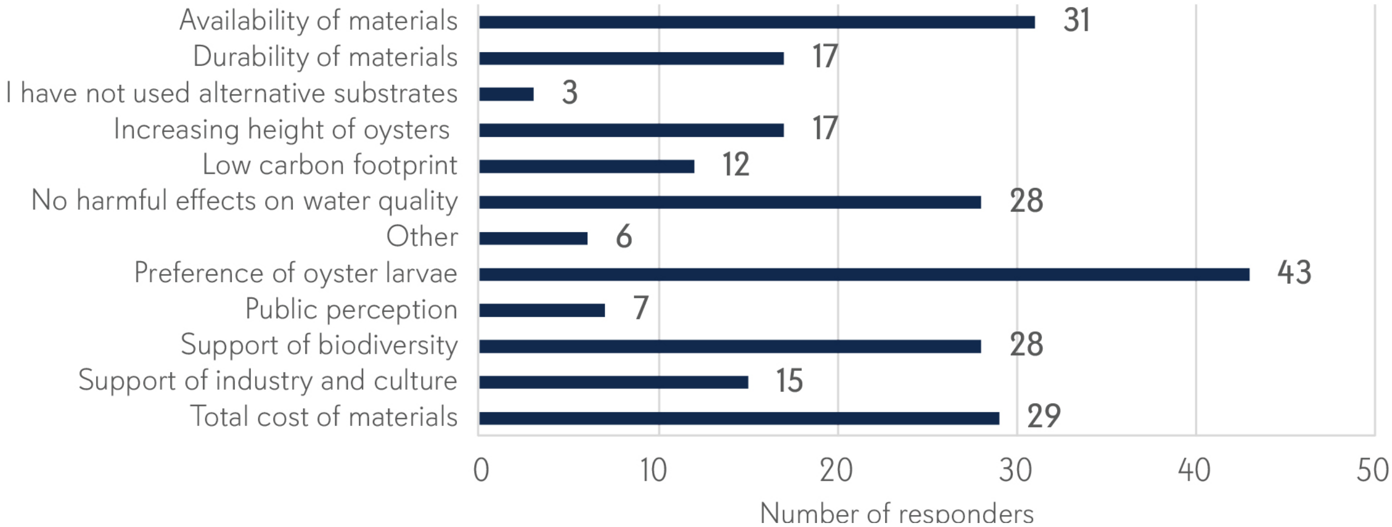


In the Other category, the following were listed:

- Reef balls
- Stone
- River rock
- Portland cement
- Quickreef crumbles
- Crab pots
- Manufactured wire reefs
- Bamboo
- Tomato stakes
- Oyster castles
- Sandbar oyster catcher
- Recycled shell
- Concrete made with shell powder
- Natural river gravel (quartzite)
- Scallop balls and blocks

Appendix B: Poll Results on Day 1

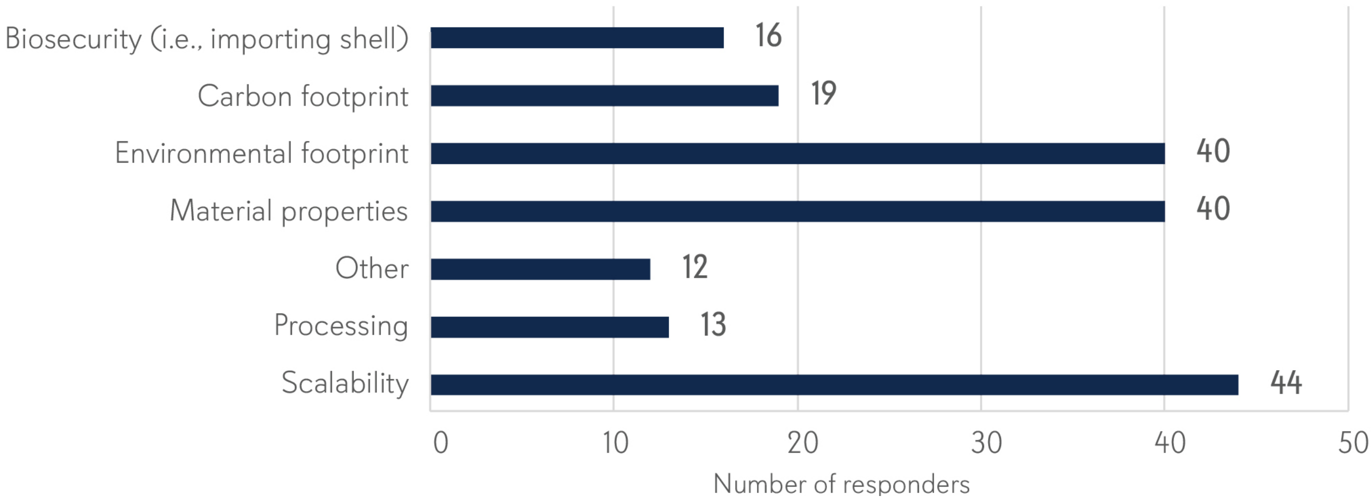
What benefits of alternative substrates are most important to you:



In the Other category, the following were listed:

- Permitting agency
- Integration into the seascape
- Ecological/habitat function
- Use of recycled concrete for living shorelines
- Use in living shoreline efforts
- Development of functioning ecosystem, rather than just fisheries
- Substrate complexity, not just surface rugosity

What aspects of alternative substrate require greater investigation? (choose your top 3)



In the Other category, the following were listed:

- Long term effects of alternative substrates
- Plastic alternative shellbags
- Constraints and creative opportunities of alternative substrates (beneficial use of dredge materials, shell "contaminants" of an offshore borrow area for beach nourishment projects)
- Preference of oyster larvae
- Food safety thresholds for potential contaminants in non-natural substrates
- Cost efficiency: delivered cost per ton/spat recruitment or market oyster yield
- Ecological function
- Fisheries impact on other species
- Contribution to ecological and ecosystem services
- Permitting pathways enter recruitment relative to cured shell
- Suitability for fishery use

Appendix B: Poll Results on Day 1

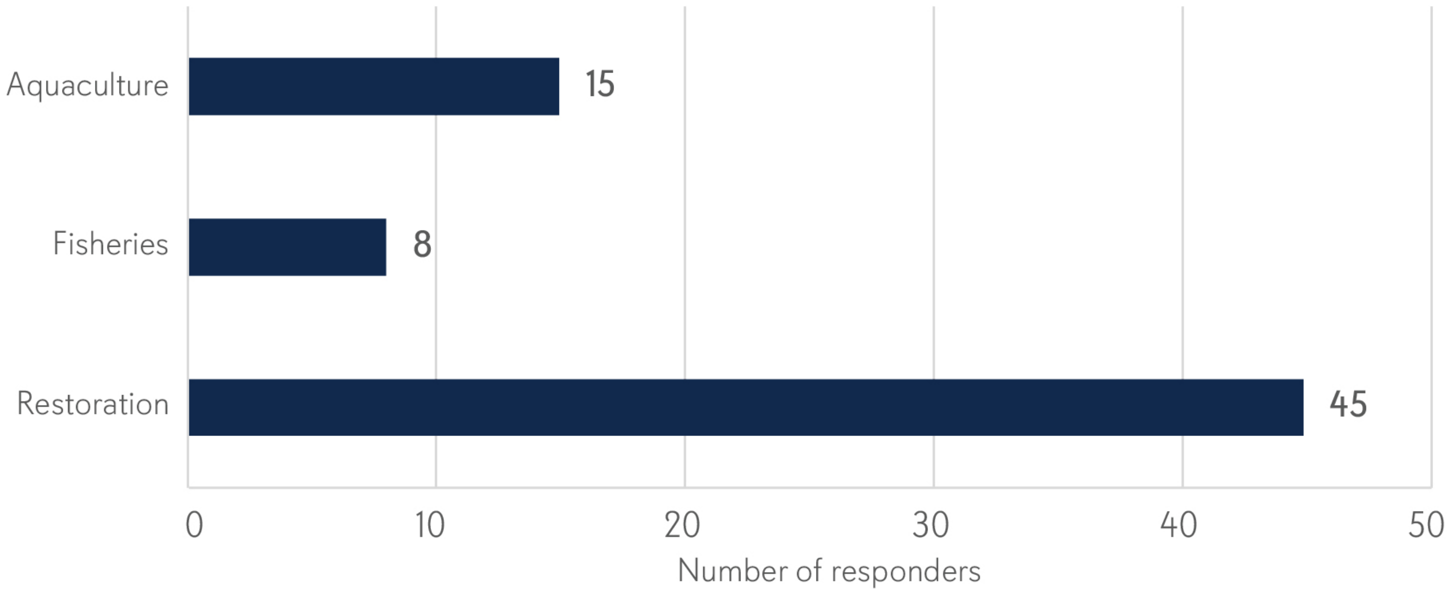
Are there issues with alternative substrate in Maryland that you think need to be addressed?

- Public perception for harvest areas for the use of rocks
- Scalability, availability and cost
- Planning for equitable access/distribution of material sourced from public domain
- Reef height necessary for effective spat recruitment
- Objective methods are needed to verify material suitability in a formal document
- Ability to take advantage of natural systems in support of harvest and non-harvest areas
- Permanence of material and practice
- Public policy analysis
- Suitability of widespread terraforming of the bay bottom

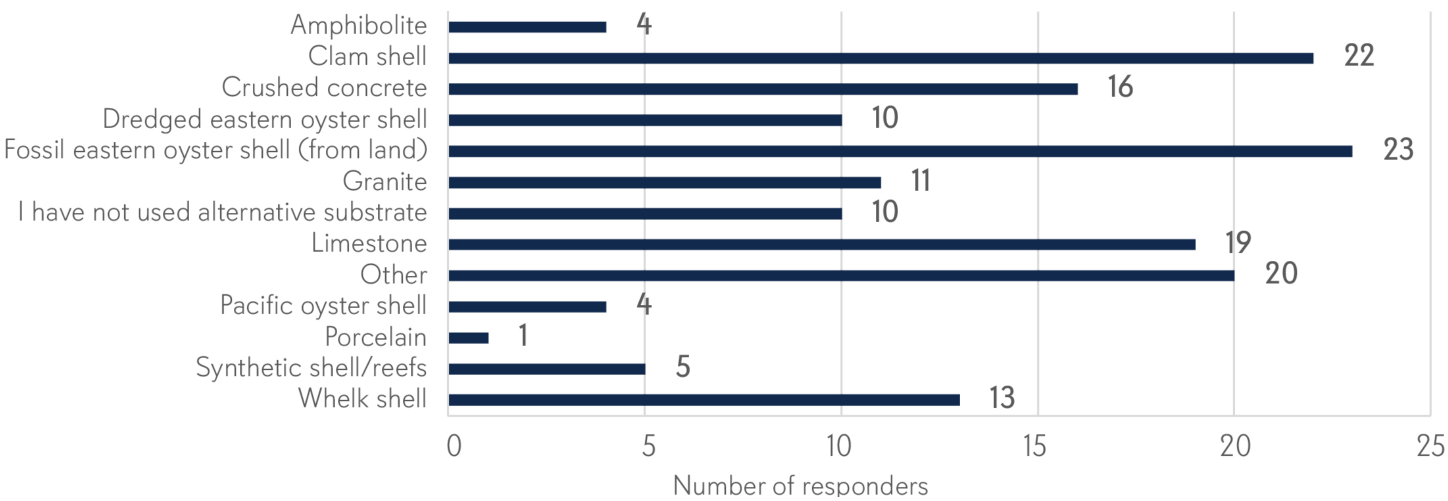
Local oystermen deploying alternative substrates experiments in Apalachicola Bay, Florida. Photo courtesy of Sandra Brooke.

Appendix C: Poll Results on Day 2

I work in the following sector(s):



What types of alternative substrates have you used? (check all that apply)

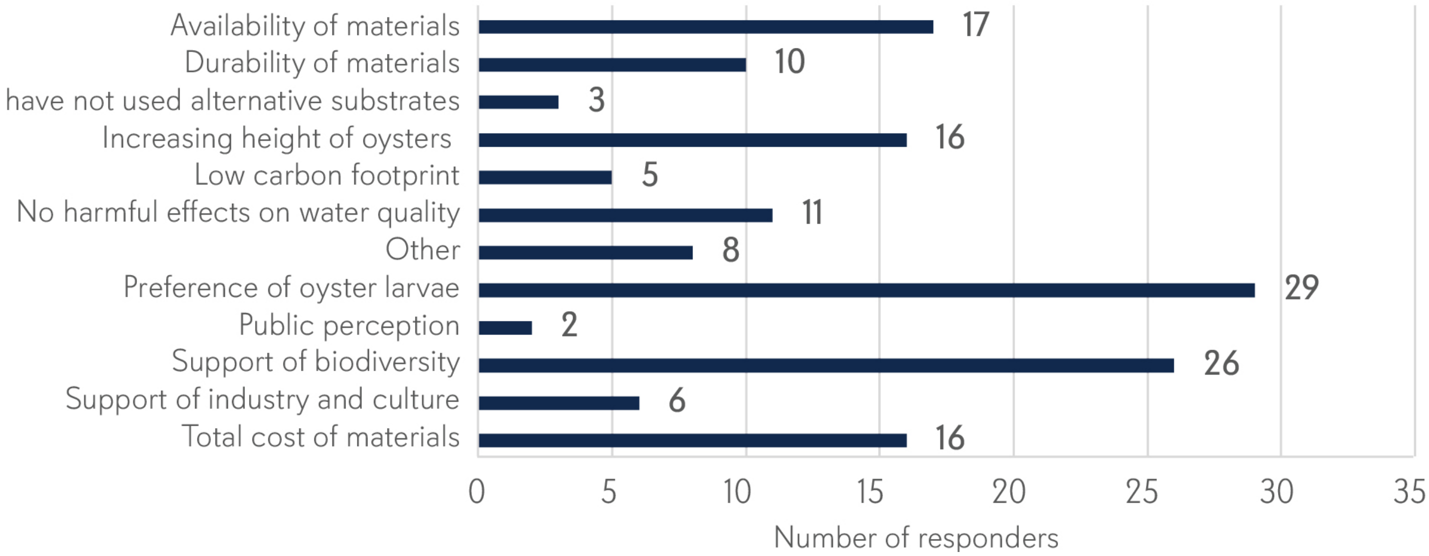


In the Other category, the following were listed:

- 3D structures made of concrete
- Reef balls
- Blue muscle shell
- Scallop shell
- Cockle shell
- Clay bricks
- Cement coated jute
- Oyster castle
- Bamboo/ wooden stakes
- Repurposed crab pots
- Tiles
- Wire mesh
- Palettes
- Porous alpha
- Slate
- River rocks

Appendix C: Poll Results on Day 2

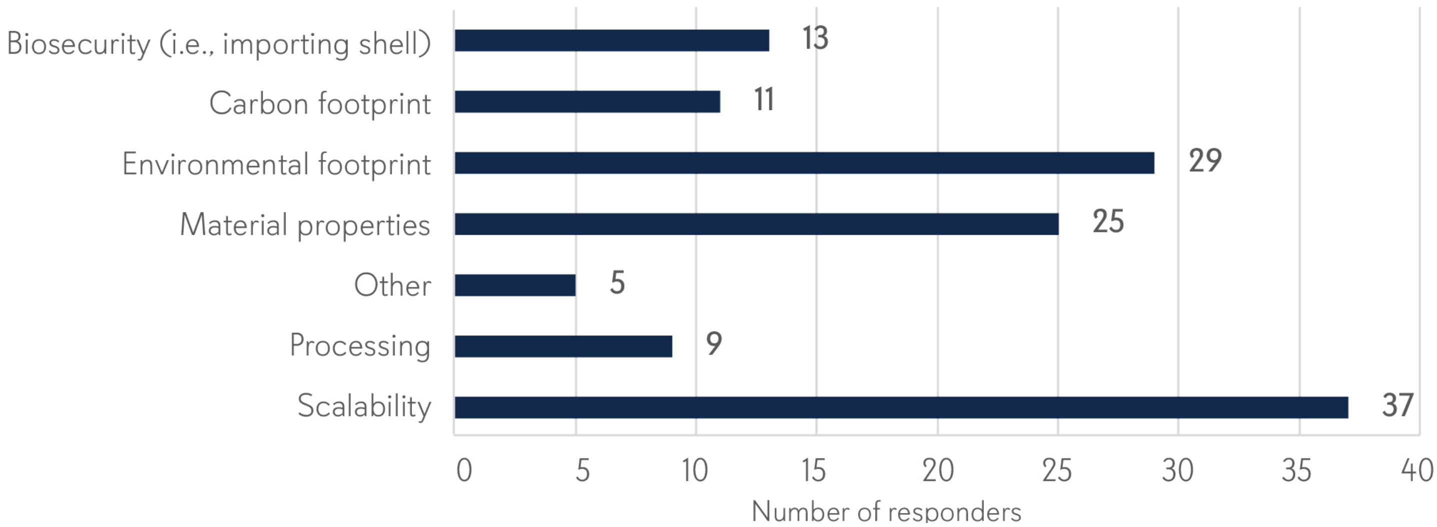
What benefits of alternative substrates are most important to you:



In the Other category, the following were listed:

- Suitability of materials
- Support of biodiversity
- Materials that promote long-term reef persistence
- A balance of all the above and scalability
- Structural complexity, not just height
- Integrate the different solutions into a cohesive package that can be clearly presented to wide audiences to justify large scale funding outside the traditional geography's

What aspects of alternative substrate require greater investigation? (choose your top 3)



In the Other category, the following were listed:

- Recruitment potential
- Integrity of installed structures
- Durability
- Sustainability
- Simulated oyster shells with porous alpha and bentonite clay
- Ecosystem goods and services

Appendix C: Poll Results on Day 2

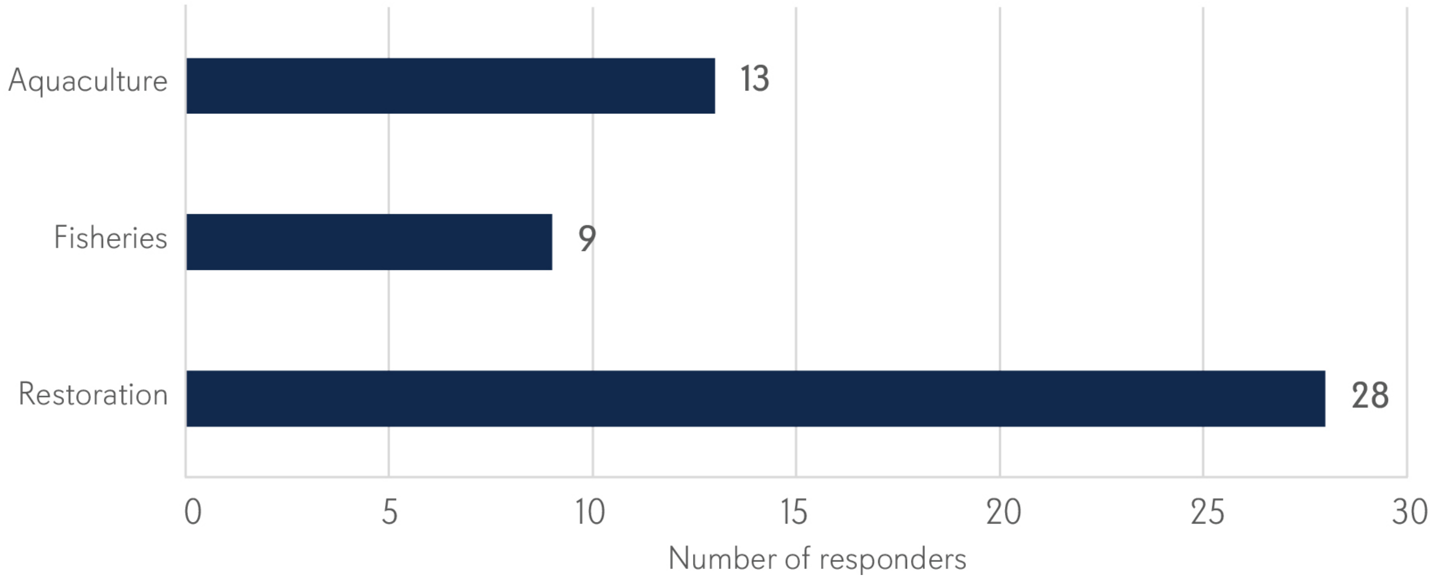
Are there issues with alternative substrate in Maryland that you think need to be addressed?

- SAV interactions
- Use of recycled concrete to reduce cost and carbon footprint
- The future of oyster gabions for restoration projects
- Public perception and acceptability
- Analysis of material performance specifically in production of spat-on-substrate
- Avoid use of plastic in oyster reef construction
- Persistence in the environment
- Need to streamline the permitting and authorization process to develop standard implementations

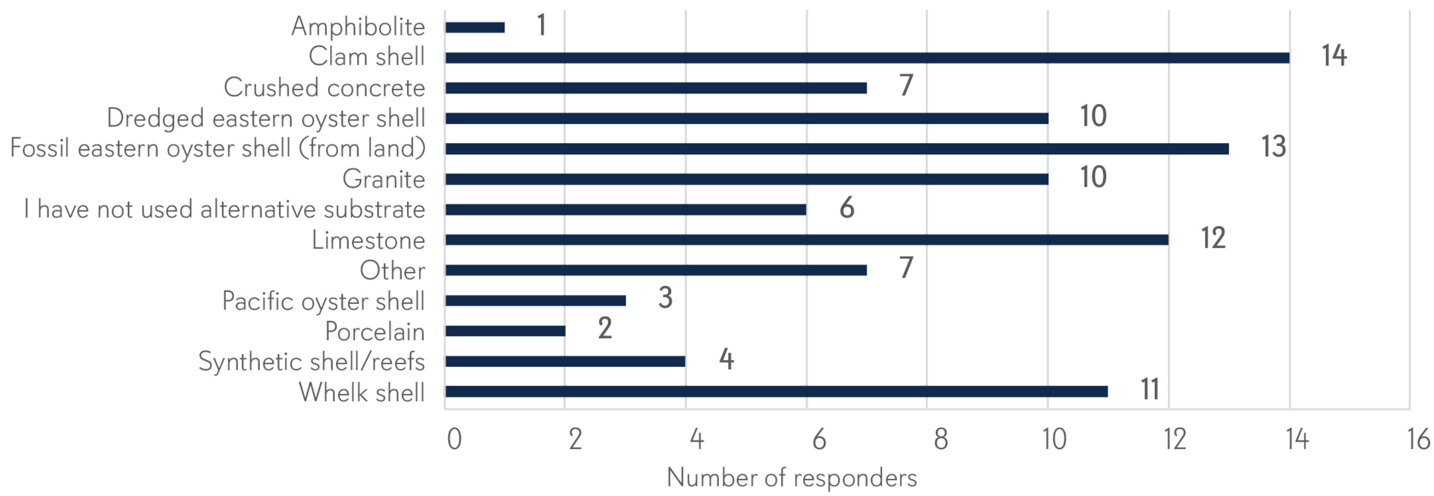
3 ft tall X-Reefs being deployed in Fort Norfolk. Photos courtesy of Russell Burke.

Appendix D: Poll Results on Day 3

I work in the following sector(s):



What types of alternative substrates have you used? (check all that apply)

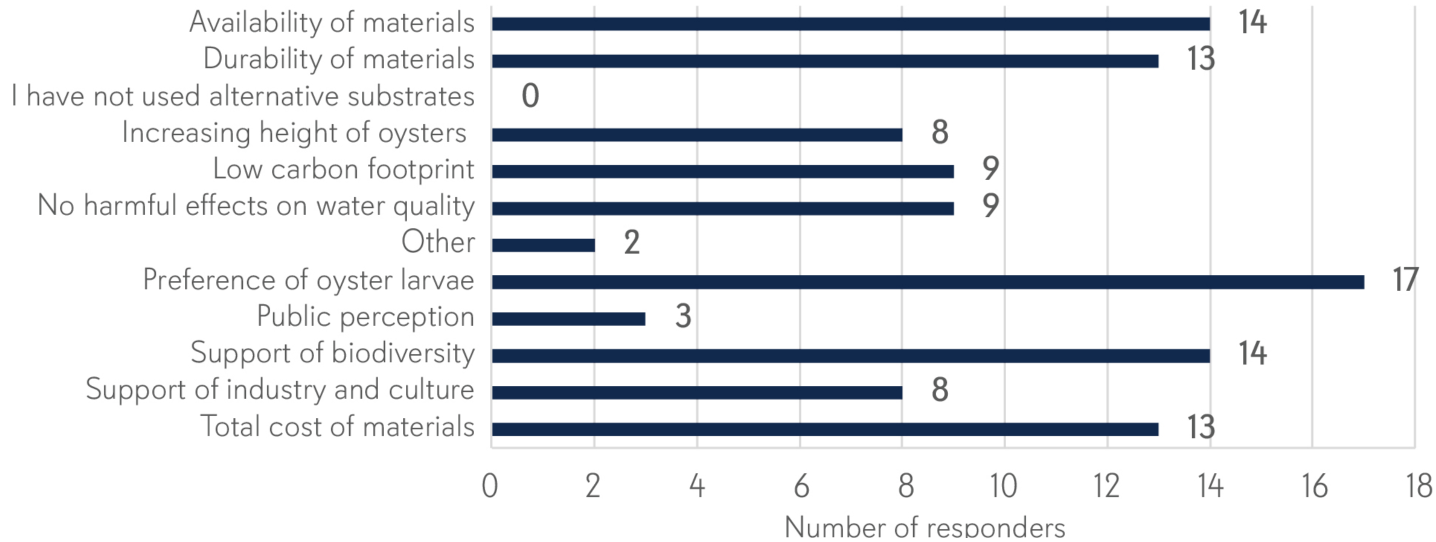


In the Other category, the following were listed:

- Reef balls
- Oyster catcher
- Cement coated jute
- Recycled concrete
- JR-CSA
- Concrete block and balls
- Foam glass tested at VIMS for settlement with success

Appendix D: Poll Results on Day 3

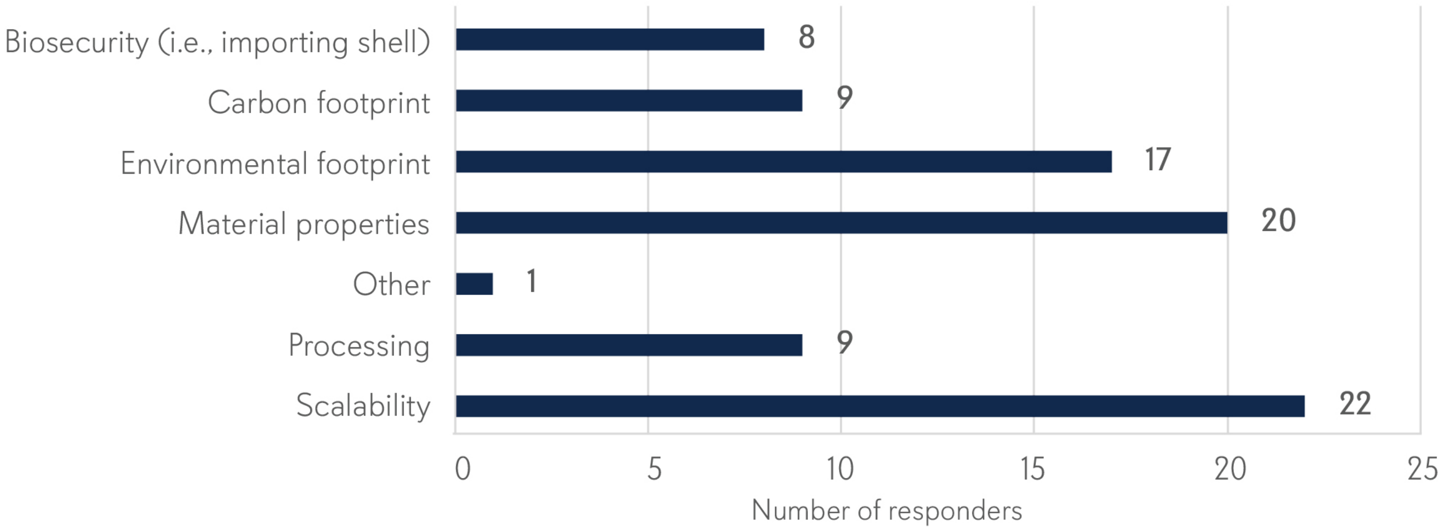
What benefits of alternative substrates are most important to you:



In the Other category, the following were listed:

- Light enough to deploy in shallow water and stable enough to endure wave energy

What aspects of alternative substrate require greater investigation? (choose your top 3)



In the Other category, the following were listed:

- Ability to adapt with rising sea level
- Simulated oyster shell
- Next step in product design and oyster farm development and cost analysis

Appendix D: Poll Results on Day 3

Are there issues with alternative substrate in Maryland that you think need to be addressed?

- Resilience of material
- Cost comparison
- Retrofitting remote setting tanks to create spat-on alternative substrate
- Maryland has collected bottle glass that can be transformed into a sustainable, non-toxic material that can help bridge the gap as increase shell collection and old shell recovery can catch up.
- The Japanese have a technology that makes toxicity of glass into the chemistry of sand. This can be added to a clay structure to keep costs low to make a shell shape or any shape you want.
- Public and all stakeholders for acceptance
- Best substrates for success in getting spat set at a reasonable cost

Jute Reinforced Calcium Sulfoaluminate (JR-CSA) in the shape of reef turtles (top), reef prisms (middle), and reef panels (bottom) upon deployment (left) and 6 months (middle) and 18 months (right) post-deployment. Photos courtesy of Mark Clark.

Sandra Brooke

Florida State University, Coastal and Marine Lab

Evaluation of materials for sub-tidal oyster reef restoration in Apalachicola Bay, Florida

In 2013 the Apalachicola Bay oyster fishery was declared a Federal Fishery Disaster, and several restoration projects were initiated to facilitate oyster population recovery. These projects maximized the restoration area by placing a thin layer of fossil shell or small (~5 cm) limestone rocks on the natural substrate. The construction goals of the projects were met, but oyster populations continued to decline. A few years after deployment, the fossil shell restoration material had deteriorated significantly and the only sub-tidal habitats that supported oysters were those restored with limestone. The Apalachicola Bay System Initiative (ABSI) is a five-year (2019–2024) multi-disciplinary project that includes research into restoration approaches for Apalachicola Bay oyster habitats, which are so degraded that the reefs have been reduced to compacted shell hash. Oysters recruiting to unstable substrate may be swept away, buried, or exposed to hypoxia, and without the structural complexity that provides refuge, oyster juveniles are exposed to predation. The ABSI conducted a series of experiments to evaluate different materials for stability and oyster population development. The first experiment tested shell, small limestone (~5cm), and larger limestone (~15 cm), which was intended to create habitat niches for predator refuge and reef community development. The reefs were constructed with ~0.5m relief and were surveyed twice annually using hand tongs. The larger limestone performed better than the other materials, so a second experiment compared limestone with cleaned, crushed construction concrete of similar size. Half of the reefs for each material had a layer of natural shell (~8 cm deep) to assess the cost-benefit of this approach. Preliminary results indicate similar performance among all treatments. Our presentation will discuss the positive and negative aspects of these approaches for large scale oyster restoration.

Russell Burke

Christopher Newport University

Large-scale implementation of shallow subtidal alternative substrate reefs as part of a comprehensive oyster reef mitigation strategy in the Elizabeth River, VA, Chesapeake Bay

The Eastern Oyster (*Crassostrea virginica*) fulfills numerous essential ecological roles in marine ecosystems, including prevention of shoreline erosion, water filtration, and provision of habitat for many marine organisms. In response to ecological functions and services that might be lost resulting from the Craney Island Eastward Expansion (CIEE) Project in Southeast Virginia, the US Army Corps of Engineers, in support of the Virginia Port Authority's (VPA) port expansion project, was tasked with supervising construction and placement of oyster reefs (2013–14) as part of a comprehensive mitigation strategy. Seven oyster reefs (16.5 acres), composed of shell, granite and prefabricated concrete structures, were placed at five sites: the Lafayette River, the Elizabeth River's Western and Southern Branches, and the Lower James River (Hoffler Creek). As part of the Project Compensation Plan, the Virginia Department of Environmental Quality (VDEQ) mandated that each of these reefs be monitored and assessed for a period of five consecutive years (2015–2020). Christopher Newport University (CNU) has overseen this program in collaboration with the Virginia Institute of Marine Science; CNU has continued monitoring the project since its implementation of an adaptive management strategy that included a number of alternative substrate reefs composed of concrete with oyster shell embedded in all outward-facing reef surfaces. By 2019, oyster density (50 oysters per m^2) and biomass targets (50 g AFDM per m^2) were exceeded across alternative substrates at all sites. In addition, CNU surveyed ~5 acres of granite breakwaters and revetments along the perimeter of Craney Island in 2022 which ultimately resulted in formal inclusion of this reef acreage within the official oyster reef compensation package. Most recently (January 2024), the CIEE project team received confirmation from the VDEQ that the oyster mitigation requirements for the associated permit had been fulfilled—a true testament to innovative project design, effective adaptive management, and inter-agency collaboration.

Mark Clark

University of Florida

Jute Reinforced Calcium Sulfoaluminate (JR-CSA)

Jute Reinforced Calcium Sulfoaluminate (JR-CSA) was developed in 2017 at the University of Florida and first deployed along Florida's central west coast in 2018. Initially developed as a plastic-free alternative to mesh shell bags and used as a low intertidal sill and wave break element of living shorelines, configuration now includes application as a high surface area substrate for oyster recruitment and habitat restoration on declining natural reefs. The material is a combination of readily available Jute erosion control mat and Calcium Sulfoaluminate (CSA) as either premixed Cement-All® (CTS Rapid Set®) or a tailored mix of CSA, sand, and water reducing additive. The CSA coated jute is then placed on a form for curing. Although the material can be arranged in almost any shape, the two principal shapes utilized are triangular prisms 30 cm x 120 cm and referred to as a "reef prism", or a corrugated panel 5 cm x 120 cm x 120 cm and referred to as a "reef panel". CSA was chosen over ordinary portland cement due to its rapid set times (20–30min), early curing strength and reduced carbon footprint. These characteristics facilitate a more efficient use of forms during production and the potential for rapid deployment. Another design objective of JR-CSA was a material where volunteers or a stakeholder labor force could readily participate in the construction process and deployment did not require specialized equipment. Since inception, the material has been deployed at over 15 sites throughout Florida and South Carolina. When compared to other substrates, JR-CSA performs very well for oyster spat colonization and growth. Depending on the CSA mix and deployment site water quality, JR-CSA can last between 18 months and at least 5 years with the original deployment site still seeing little or no degradation of the material.

Chris Karawacki

C.J. Karwacki Consulting, LLC

Biomimetic nacre-like material for recruitment and growth of oyster spat

Watermen and scientists have observed for many years the strong dependence of shell mass on oyster recruitment rate and abundance across several destabilizing factors, such as disease, natural mortality, and fishing. Today there is an urgent need for suitable alternative nacre like materials that can offset the decreasing supply of natural oyster shell used for the recruitment and growth of oyster larvae in the Chesapeake Bay and surrounding estuaries. Here we discuss an approach to develop a material that mimics the natural oyster shell's chemical composition, structure and cueing properties for the setting and growth of oyster larvae with the aim to maximize the recruitment and growth of oyster larvae throughout their life cycle. Natural oyster shell is formed by a biological-driven process involving sequencing of water-borne calcium and magnesium ions, carbonic acid, amino acids, and chitin to form a layered assembly of fortified crystalline calcium carbonate. During the transitional assembly of calcium hydroxide to amorphous calcium carbonate, calcium ions bind at oxygen centers on amino acids such as aspartic and glutamic acids to form ionic/covalent bonds that significantly strengthen the bulk structure compared to calcium carbonate alone. Amino acids in combination with magnesium ions influence the formation of specific forms of crystalline calcium carbonate (node), such as aragonite while retarding formation of calcite. Finally, chitin is synthesized *in situ* and systematically excreted to form an encapsulated organic sheath (linker) across layers of crystalline calcium carbonate. Chemical binding with oxygen centers on the chitin to calcium ions further increases the strength of the bulk shell while providing a protective barrier.

Jay Lazar

National Oceanographic and Atmospheric Administration

Applying a novel oyster reef habitat quality monitoring methodology in Harris Creek, MD

2021 marked the end of formal monitoring for the Harris Creek large-scale oyster restoration project, the first of five in MD. Challenges with comparing results across treatment types arose from using two sampling gears, patent tong and diver. A novel video based approach to score habitat quality with one gear type was created by the Smithsonian and applied across all reefs in Harris Creek during summer 2022. The study used a video based rapid assessment protocol to assess the impact of different restoration treatments on oyster reef habitat quality in Harris Creek. Sites included seed-only, mixed shell and variations of stone substrates within the sanctuary and harvest areas outside the sanctuary. We conducted field sampling to collect underwater GoPro photos at each site. We then assigned each site a qualitative habitat score from 0–3 based on oyster shell coverage and reef height (oysters growing vertically), with 3 indicating the highest quality habitat.

Of the 574 sites sampled over 8 days, 84% (484) were usable with an average of 20 samples collected an hour. Sites restored with stone treatments had the highest proportion of 3 scores (93%), followed by mixed shell (71%), seed only (62%), unrestored sanctuary sites (14%), and unrestored harvest sites (5%). These results suggest that there may be benefit to stone treatments for future oyster reef restoration efforts, as stone treatments may provide more surface area for larval recruitment and the interstices act as a sink to sediment, providing longevity to the available recruitment surface. Additionally, the rapid assessment protocol proved to be a viable alternative monitoring tool to understand sedimentation, observe and catalog reef evolution and potentially do so in a more efficient manner. Together, our study provides a clearer image of Harris Creek post-restoration and a method to compare the future condition of the restored tributary.

Niels Lindquist

Sandbar Oyster Company Inc

Use of Oyster Catcher™ substrates for facile setting of oyster larvae and relaying of juvenile oysters

The long-term success of oyster habitat restoration efforts is dependent upon reliable stocking via natural recruitment and/or seeding. With global climate change accelerating sea-level rise, salinity levels of many estuaries are increasing and thereby shifting areas conducive to sustainable subtidal reef development farther up estuaries (Tice-Lewis *et al.* 2022, *Ecol. Appl.*). While potentially opening vast areas previously devoid of reefs to reef development, these up-estuary shifts may incur recruitment limitation if estuarine waters replete with larvae aren't reliably transported to the sites. Additionally, these areas may be at high risk for prolonged freshets that could periodically cause mass oyster mortality and create the need to seed reefs located where levels of natural recruitment are low. For millennia, recruitment limitation has been overcome by seeding cultch and transporting spat-coated materials from areas of high oyster recruitment to areas of low recruitment. Oyster shell and stone materials have long been used for seeding and relay, but various features of these materials may limit their utility, including weight, relatively low surface area/volume ratios, bulk and handling logistics. Sandbar Oyster Company (hereafter SANDBAR) is pioneering the use of cement-infused plant cloth substrates having features and benefits ideal for facile seeding and relay of vast numbers of juvenile oysters. These proprietary, patent-pending substrates are trade named Oyster Catcher™. The "Tuft" form of Oyster Catcher™, which is shaped like a three-dimensional pretzel, is light-weight, has a very high surface area/volume ratio, is easily handled and degradable. The latter feature allows spat-covered Tufts to break apart and detached oysters to disperse thereby lowering mortality associated with tightly clustered oysters. This presentation introduces SANDBAR's use of Tufts seeded with wild spat to source juvenile oysters into oyster restoration projects (*e.g.* New River Estuary Oyster Highway) and aquaculture. Tufts have also been successfully seeded in a hatchery setting.

Rom Lipcius

Virginia Institute of Marine Science

Ecosystem-based planning, implementation and success of subtidal, granite oyster reefs in the Piankatank River, VA, Chesapeake Bay

Although oyster restoration practitioners have adopted alternative reef substrates for projects in subtidal waters, a comprehensive strategy for this approach has not been fully developed. As part of the Chesapeake Bay Native Oyster Recovery Project, the USACE constructed a large subtidal granite reef in the Piankatank River (PR) of lower Chesapeake Bay. We describe a restoration strategy implemented in the PR, which included (i) hydrodynamic modeling of metapopulation connectivity, (ii) field validation of connectivity, (iii) habitat suitability modeling, (iv) high-resolution benthic habitat mapping, (v) historical data on oyster distribution, (vi) reef geometry proven to be successful, and (vii) surveys of oyster and mussel abundance on the reefs to examine restoration reef performance. Based on the hydrodynamic model, mid- to down-river reaches could support a source metapopulation that self-sustains and exports larvae to sink habitats farther downriver and outside the mouth. Upriver segments would not receive larvae despite availability of suitable habitat, which was validated by field surveys. Two years after construction, the reef network harbored a dense population of age-0 juveniles and age-1 adults. Adult oyster density averaged 219.3 per square meter and biomass 75.3 g dry weight per square meter. Mean live mussel density was also high at 194.5 per square meter. Mean live oyster volume was 3.2 L per square meter and consistent with a positive shell budget, even though it was an underestimate because it did not include the volume of underlying reef base of oxic dead shell normally aggregated with live oyster shell volume. ROV video corroborated high species diversity from lab samples, which included shrimp, fish, crabs, clams, snails, mussels and sponges. Several predatory fish species were on the reef, while crustaceans, including blue crabs, mud crabs and shrimp, were walking and feeding on the reef surface, indicating a successfully restored oyster reef community.

Hunter Mathews

University of North Florida

Early performance of the Pervious Oyster Shell Habitat (POSH) in restoring intertidal habitat for oysters and associated nekton along energetic shorelines in northeast Florida

The "Pervious Oyster Shell Habitat" (POSH) is a novel artificial reef structure designed to minimize pollution and provide quality oyster habitat in high-energy systems. The POSH is composed of oyster shell bound by a thin layer of portland cement, into a dome. POSH modules were compared *in situ* to the industry standard "Oyster Ball" model Reef Ball™ for oyster recruitment and utilization by fish and crustaceans. The study took place from June 2021 to June 2023, along two energetic shorelines in northeast Florida: Kingsley Plantation along the Fort George River (Duval County) and Wrights Landing along the Tolomato River (St. Johns County). Oyster demographics and densities were assessed on the structures throughout the first year of deployment. Nekton densities and communities were assessed throughout the second year, using $2m^2$ bottomless lift nets. Artificial reefs were compared to an adjacent oyster reef at Kingsley Plantation. Oyster recruitment was significantly greater on the POSH compared to the Oyster Balls at both Kingsley Plantation ($p < 0.000$) and Wrights Landing ($p < 0.01$). Fish densities did not differ among treatments at either site ($p > 0.05$). At Kingsley Plantation, crustacean densities were significantly greater on the natural oyster reef than both artificial reef structures ($p < 0.01$), excluding with the Oyster Ball in winter ($p = 0.263$). Densities were significantly greater on the POSH than the Oyster Ball during summer ($p < 0.001$), fall ($p < 0.001$), and spring ($p < 0.0001$), and greater on the Oyster Ball in winter ($p < 0.05$). At Wrights Landing, crustacean densities were greater on the POSH in summer ($p < 0.0001$) and spring ($p < 0.05$). Fish and crustacean diversity metrics were similar among treatments at both sites. Early findings for the POSH indicate that it can be a viable method for rapidly restoring oyster reef communities in high-energy systems.

Doug Munroe

North Carolina Division of Marine Fisheries

North Carolina's use of alternative substrate for cultch planting in support of oyster rehabilitation strategy

North Carolina has been utilizing various materials to construct low-relief (< 1') oyster cultch reefs since 1915. These efforts are designed to support the state's oyster restoration program. Cultch sites provide a suitable substrate for larval oysters to settle and develop on in North Carolina's estuarine waters. Due to limited availability of oyster shell, the Cultch Planting Program has adapted the use of alternative material types. Shell only accounts for 10–20% of total materials deployed on cultch sites constructed since 2018, while materials such as limestone marl and crushed concrete, which are more readily available, have taken the place of oyster shell in the construction of cultch reefs. North Carolina constructs 40–50 acres of cultch reefs annually, which are opened to commercial harvest, once the oysters on the reefs have grown to harvestable size. Cultch sites support valuable biological and ecological functions, are designed to help reduce overall fishing pressure on natural oyster reefs and create additional opportunities for commercial fishermen to harvest oysters.

Bennett Paradis

North Carolina Division of Marine Fisheries

North Carolina's oyster sanctuary program: restoring Pamlico Sound's subtidal oysters with artificial reefs

Beginning in 1996, North Carolina's Division of Marine Fisheries has been investing in the construction and monitoring of no-take oyster sanctuaries with the intention of subsidizing larval availability in Pamlico Sound. In total, 17 large scale artificial reefs covering 566 acres of protected habitat have been built by deploying 223,640 tons of various materials. While most of these sanctuaries were built with marl limestone rip-rap, other materials have also been used including reef balls, granite, basalt, crushed concrete, recycled concrete pipe, and a variety of recycled shells. Annual monitoring of the sanctuaries provides high resolution data into the performance of each site in terms of oyster density and population structure. The long-term dataset has given managers and biologists valuable insight for comparing materials, salinity regimes, and reef design across time, guiding future large scale oyster restoration projects.

Matt Pluta

ShoreRivers

Natural recruitment to alternative substrates in the Tred Avon River: a pilot study

Oyster shell represents a critical resource for restoration, aquaculture, and fisheries in the Chesapeake Bay. The exploration of alternative substrates, as substitutes for natural oyster shells, to capture spat and facilitate recruitment is gaining significant attention. While numerous potential alternative substrates exist, only a limited number have undergone testing in field conditions during natural spat fall events. In our study, we deployed replicate platforms, each hosting 12 different substrates, including oyster shell, clam shell, and various building materials such as brick, granite slabs, ceramic tile, etc., that have been suggested for potential large-scale use. These platforms were strategically placed in three distinct sites within Tred Avon River during the summer of 2021, coinciding with a notably favorable year for oyster recruitment in the Maryland portion of the Bay. At the end of the study, eight of nine platforms were retrieved, gently cleaned, and photographs of each substrate were meticulously taken. Utilizing image analysis, we recorded oyster recruits across the different substrates. Oyster spat exhibited a higher affinity for oyster shells, with clam shells following closely. Conversely, the remaining tested materials did perform nearly as well in attracting oyster spat. The study demonstrated a preference for shell but we also noted many oysters recruited to the underside of the plastic platform supporting the tested materials on the surface. These and other study details will be discussed.

William Rodney

Texas Parks and Wildlife Department

A summary of TPWD oyster restoration activities utilizing alternative cultch materials

Since 2007, Texas Parks and Wildlife Department's (TPWD) Coastal Fisheries Division has been actively working to restore oyster reefs for the purpose of enhancing the oyster fishery as well as the ecosystem services that these critical habitats provide. These efforts began in 2007 when TPWD received an appropriation from Congress in response to impacts from hurricanes Katrina and Rita. As of 2023, $16 million has been spent and more than 600 acres of oyster habitat has been restored through cultch planting. About 95% of TPWD's restoration efforts were completed in commercially harvestable waters and thus directly benefited the commercial oyster industry. The remaining 5% was placed in waters that are closed to commercial harvest, and thus provided enhanced ecosystem services. Over the years, a variety of substrate types and design approaches have been successfully employed. Substrates have included river rock, recycled crushed concrete, and crushed limestone of various sizes. Designs have featured flat layers with low vertical relief and mounds with moderate vertical relief. Decisions on cultch types and design approaches were informed by restoration goals. Several projects utilizing different cultch types and designs are discussed.

David Schulte

US Army Corps of Engineers

Lynnhaven River, VA results of large-scale reef ball-based oyster restoration

In 2021, a large network of reef balls (28,500), each 0.4572 m (1.5 ft) wide and 0.3048 m (1.0 ft) tall covering 8.0 acres of subtidal, sand/clay/silt mix bottom in the polyhaline waters of the Lynnhaven River, VA, the most southeastern tributary river of Chesapeake Bay. The site selected was determined by both historical documentation as well as modern-day hydrodynamic modeling to be a good site for reef construction. Monitoring results have demonstrated the reef ball system, despite its young age, already is well in exceedance of Chesapeake Bay Program goals for oyster density and biomass, and exceeds the more ambitious goals of the Lynnhaven River Ecosystem Restoration Plan written by the USACE. At present, the three-dimensional reefs have a mean of 1137.6 ± 94.99 SE g/m^2 DM oyster tissue, 4,275.1 live oysters/m^2/river bottom area, consisting of 2,884.3 ± 240.23 SE spat and 1390.8 ± 104.85 SE adults. Live shell volume was also exceptionally high at 40.1 ± 2.80 SE l/m^2/river bottom area. The largest oysters observed on the reef balls were over 150 mm in shell height. These results suggest that oyster restoration using alternative materials in subtidal, polyhaline waters of Chesapeake Bay can produce exceptionally good results, and suggests that such alternative material based efforts can greatly assist in oyster restoration efforts in Chesapeake Bay.

H. Ward Slacum Jr.

Oyster Recovery Partnership

Advancing alternatives to shell for oyster production

Natural oyster reefs depend on shell accretion for long-term growth and survival, and their restoration is dependent on the availability of oyster shell as substrate for successful recruitment. In most coastal environments, shell loss has been accelerated by fishing activities and increased sediment deposition. To account for this, management agencies encourage initiatives to expand oyster production through aquaculture, public fishery management activities, and oyster restoration. This three-pronged management approach has increased the demand for shell, and availability is insufficient to meet demand. There are several ongoing initiates underway in Maryland to identify alternatives and alleviate the demand for native shell resources.

Kathy Sweezey

The Nature Conservancy

A discussion on the challenges of using alternative substrate: a project manager's perspective

Despite the many benefits they provide, oyster reefs are one of the most imperiled marine habitats on earth. Globally, over 85% of oyster reefs have disappeared. Oyster populations in Texas are at a historic low, emphasizing the need for oyster reef restoration and protection efforts.

Restoration practitioners face many challenges including the increasing cost of commonly used "traditional" substrate like shell or limestone, limited availability of traditional substrate near project locations, and increased emissions to transport and deploy substrate for the project. Alternative substrate provides an opportunity to address each of these challenges and potentially leads to additional benefits and a more effective way to reach project goals.

Beezley Reef is a 40-acre subtidal oyster reef restored by The Nature Conservancy in Galveston Bay, Texas. This reef has a unique design as a hybrid part harvestable, part sanctuary reef complex. During the second phase of this project which focused on expanding the sanctuary reef by two acres, project managers emphasized the desired preference for alternative substrate with the engineer and in bid documents. However, the low number of bids returned, the cost of the alternative substrate bid obtained, and the limitation of alternative substrate that could be used on a subtidal reef all led to the decision to restore the reef using traditional substrate, limestone. Project managers met with multiple alternative substrate providers during the design phase to discuss Beezley Reef, assess feasibility, and gauge interest. Unfortunately, the providers met with were either unable to support a subtidal oyster reef or did not bid on this project.

For discussion, project managers ask: How do other practitioners seek alternative substrate providers? What alternative substrates are available for subtidal oyster reef restoration? How can restoration practitioners and alternative substrate providers enhance collaboration to best reach the project goals within limited budgets?

Christine Thompson

Stockton University

Optimizing remote setting on different cultch types for oyster restoration in Barnegat Bay, NJ

Restoration efforts for the eastern oyster, *Crassostrea virginica*, are often limited by sources and availability of cultch for remote setting. In Southern New Jersey, a shell recycling program has been created to provide shell for restoration purposes, but the types and availability of shell can vary. Additionally, the growth of oysters on these shell types once planted may affect restoration success if set ratios are too high or low. This study evaluated the average settlement of eyed oyster larvae in circular setting tanks with mixtures of three shell types: eastern oyster (*C. virginica*), surf clam (*Spisula solidissima*) and knobbed whelk shell (*Busycon carica*). Spat settlement was assessed prior to deployment on the subtidal reef site and again four months post-planting. Initial settlement numbers (no. oysters per shell) significantly differed between each shell type and were highest for surf clam shell and lowest for whelk shell ($p<0.001$). During post-planting monitoring, oysters and surf clam shell had the largest oysters but also had the highest mortality. This study is important for optimizing aquaculture techniques for both large and small-scale remote setting that can be restricted by both the availability of shell types and permitting requirements prohibiting certain substrates in shallow-water bays.

Appendix E: Abstracts

Jennifer Zhu

Billion Oyster Project

Innovative approaches in oyster restoration: exploring alternative materials and substrates in the New York Harbor

With a growing focus on microplastics and individual and collective carbon footprints, many restoration practitioners and innovative suppliers are actively exploring alternative materials for application in marine restoration projects. Billion Oyster Project is enthusiastic about ongoing research and collaboration with industry professionals to understand how these materials can enhance oyster restoration efforts throughout New York Harbor. This presentation highlights the alternative materials and substrates that have been applied to oyster restoration projects since 2016.

Materials such as coir, burlap, and biodegradable mesh offer an eco-friendly alternative to the conventional plastic mesh bags used in bagged shell reef oyster restoration. However, their biodegradability often occurs at a pace that exceeds the time required for an oyster reef to develop. Burlap bags have degraded before oysters could cement to each other and form reefs. Some biodegradable meshes may also still leach microplastic material faster than traditional nylon bags. Further research is needed to understand how long biodegradable bags take to break down in marine environments and provide insight into their applicability across restoration projects and community engagement and education programs.

Alternative substrates seeded with oysters, such as reef balls and ECOncrete® disks are widely applicable restoration techniques with longer lifespans to sufficiently support the establishment of oyster populations at restoration sites. Cement is a primary ingredient in these concrete structures, which extends the lifetime of the structure but is more carbon-heavy. This can be offset through the addition of aggregates, such as rocks or shells, to the mixture. Structures such as piling wraps to attract wild oysters to settle on bulkheads have shown short-term success in the harbor, but are challenging to install and maintain. In New York Harbor, these types of applications are better suited for habitat enhancement than habitat creation. Hard substrate such as reef balls provide more surface area on which oysters can grow, and are easier to monitor, making them more optimal for use in oyster restoration projects.