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Role of Sea Grant in Establishing Commercial Oyster Aquaculture through Applied Research and Extension

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Abstract: Sea Grant programs, both separately and in collaboration, have supported growth of the off-bottom oyster industry in all five U.S. states in the Gulf of Mexico. Here, we review the history of the Mississippi-Alabama Sea Grant Consortium (MASGC) investments in research and extension to support the growth of this industry (particularly in Alabama and Mississippi). Notably, the integration of applied research with strategic extension efforts was essential to the success of this industry. The MASGC enabled the establishment of commercial off-bottom oyster aquaculture in Alabama and Mississippi using a series of strategic, outcomes-focused investments in applied research and extension efforts through an array of partnerships. In Alabama, the first commercial off-bottom oyster farm was established in 2009. The industry grew to 22 farms by 2020 with a farmgate value of nearly $1.5 million, employing over 30 full time equivalents (FTE). Over 12 farms have been established in Mississippi in the last two years. The MASGC also leveraged additional support from other funding agencies that has multiplied the outcomes and impacts.

Keywords: *aquaculture, oyster, outcomes, applied research, extension*

Off-bottom oyster farming refers to the culture of oysters usually held in some type of mesh containers (basket, bag, cage, etc.) that are kept above the seafloor (Figure 1). Oysters grown this way are typically hatchery-reared, single-set oysters instead of the clumps of oysters normally found in the wild. When properly operated, the containers provide protection from predators and eliminate burial in sediment, allowing oysters to be cultured in areas where oysters would not survive on the bottom (e.g., high salinity areas where predation rates are very high or where the substrate is too soft). Off-bottom oyster culture is distinct from public commercial and recreational fisheries on public oyster beds and traditional on-bottom oyster farming on private oyster grounds. Off-bottom oyster culture focuses on commercial harvesting, unlike oyster restoration efforts focused on establishing reefs for the various ecosystem services that they provide, and oyster gardening, which is non-commercial culturing of oysters often associated with restoration efforts (see Walton et al. 2013a for a more detailed description of off-bottom oyster farming on the coast of the Gulf of Mexico).

While off-bottom culture of oysters is well established on the Atlantic and Pacific coasts, both globally and domestically, this technique is relatively new to the Gulf of Mexico. In contrast, on-bottom culture has been practiced throughout the region from Texas to Florida and is the predominant method of production in Louisiana and Texas. On-bottom oyster farming in the Gulf of Mexico typically relies on management of private oyster grounds, which includes placing cultch (oyster shell, limestone, etc.) on an oyster reef to harden the substrate and relies on recruitment of wild oysters via spat fall that attaches to the cultch. While on-bottom culture in the Gulf of Mexico allows for very high levels of production,

Research Implications

- Investments by the Mississippi-Alabama Sea Grant Consortium (MASGC) enabled the establishment of commercial off-bottom oyster aquaculture in Alabama and Mississippi.
- Through partnerships and collaboration with other Sea Grant programs, the Cooperative Extension System (CES), and other partners, these investments helped commercial off-bottom oyster aquaculture become established throughout the U.S. Gulf Coast.
- This case study suggests that a combination of applied research projects, extension projects, and ongoing extension efforts, as exemplified by the MASGC's approach to off-bottom oyster farming, can yield measurable outcomes with significant impacts in communities.

production levels are also highly cyclical, subject, for example, to high levels of predation, dramatic salinity changes, and/or years of poor recruitment. Because the oysters form irregular shapes, these oysters are primarily targeted for the shucked market (Walton et al. 2013a).

Off-bottom production systems take advantage of the availability of food (phytoplankton) throughout the water column. Because farmers have more control over the farming practices, off-bottom production systems have the following potential advantages over other production methods like bottom culture (Walton et al. 2013a):

- Promote faster growth by raising oysters in food-rich waters and controlling stocking density within a cage or bag;
- Increase survival by providing protection from predators, burial, and potential anoxia at the seafloor;
- Allow control of fouling (e.g., barnacles, overset oysters, mud worms);
- Improve shell shape and appearance, using various culture techniques; and
- Increase product consistency.

Oysters produced using off-bottom culture techniques are typically sold to the premium half-shell market by count. Off-bottom culture of oysters requires significant investments of time, labor, and money, but has the potential to provide a consistent supply of premium quality oysters for the half-shell market. In contrast, traditional on-bottom production from either public oyster reefs or private oyster grounds yields larger quantities of oysters that obtain lower prices. On-bottom oysters are sold by weight or volume and are primarily intended for the shucked meat market.

Growth of Off-bottom Oyster Farming in the Gulf of Mexico

Off-bottom oyster farming was attempted in the 1990s in Alabama and Florida but was rejected due to concerns about the high labor costs and ability to get a profitable price (C. Nelson, Bon Secour Fisheries, pers. comm.). With a series of public and private investments, collaborative research, and extension efforts (described below), commercial off-bottom oyster farming was initiated in 2009, with one commercial oyster farm each in Alabama and Louisiana.

Initially, growth of the industry was slow and confined to Alabama and Louisiana. With the first harvest and sales in 2010, interest began to grow. As of 2019, there were 31 farms in Alabama and eight farms in Louisiana (R. Grice, pers. comm.). In 2015, Florida implemented regulations that allowed the use of the water column for oyster farming, leading to a rapid increase in the number of leases permitted to produce oysters with off-bottom methods (Walton, pers. obs.). In 2018, Mississippi permitted a zone for off-bottom aquaculture and began training classes for oyster farming, with the first commercial farms in operation in 2019. In 2018, Texas changed the laws to allow off-bottom oyster farming, and permit applications are currently under consideration.

From 2010, regional production has generally increased (Table 1) and is now around 12% of total off-bottom oyster production in the southern U.S. (which is dominated by Virginia). This rapid rise in regional production has been fueled by both an increase in the number of farms producing oysters and the increase of production per farm, with variations within each state. There also have been numerous challenges to the industry that have led to drops in production, including environmental challenges (tropical storms, freshwater events, rainfall closures, etc.), regulatory hurdles, unusual

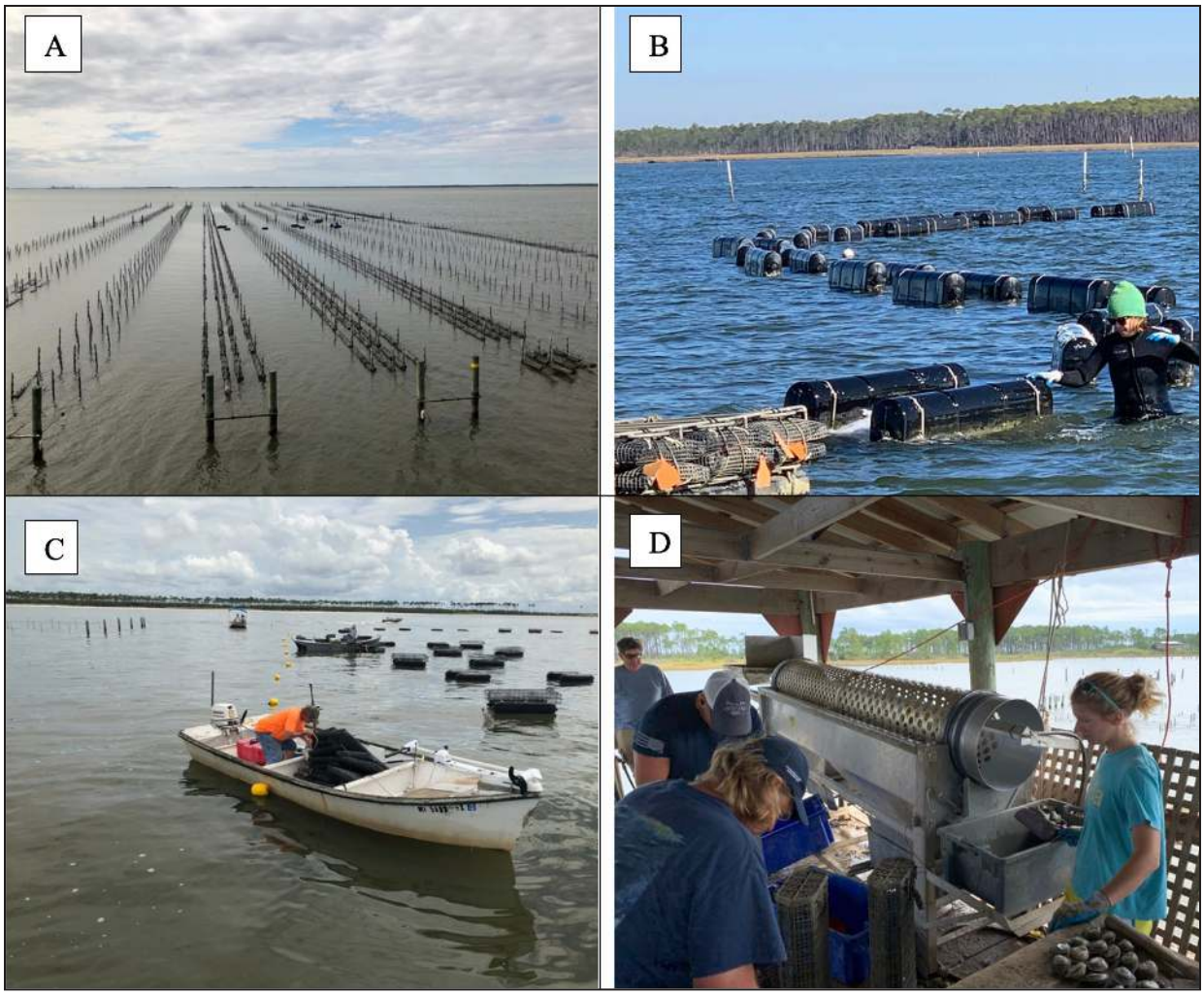

Figure 1. Off-bottom oyster farming in the Gulf of Mexico, illustrating common culture methods and grading. A.) Adjustable long-line system farm in Alabama. B.) Working floating cage system, with one cage (forefront) flipped up to allow oysters and gear to air-dry (Alabama). C.) Working floating cages from a boat at a Mississippi training area. D.) Grading, sorting, and splitting oysters with a mechanized tube sorter at a commercial farm in Alabama.

crop mortality events (including mortalities associated with the use of triploid oysters), and most recently the Covid pandemic, with the closures of restaurants and raw bars imposed in most states (van Senten et al. 2021).

There is no doubt that several factors, organizations, and individuals have contributed to the establishment and growth of commercial off-bottom oyster aquaculture in Alabama and Mississippi (and the U.S. Gulf Coast more broadly). However, we believe Sea Grant programs (in partnership with industry, the CES, academia, and regulatory agencies) played a critical role, with investments in applied research and extension. Here we review the timeline of the investments made and then discuss the implications of this case study.

Timeline of Investments

Assessment of Feasibility

The concerns raised about the commercial feasibility of off-bottom oyster farming hinged on two factors: the labor costs associated with controlling the heavy overgrowth by other organisms such as barnacles and seaweed (bio-fouling), and concerns about market price. To address the first issue, the Mississippi-Alabama

Table 1. Current best available data for recent off-bottom oyster production by millions of pieces in U.S. Gulf of Mexico, with Virginia and the southern U.S. total (Maryland south to Texas) for comparison.

Year	Estimated Off-bottom Oyster Production, Pieces (Millions)								
	AL	FL	LA	MS	TX	Gulf of Mexico Total	VA	US South Total	Gulf of Mexico Percentage
2013	ND	0	ND	0	0	0	31	33.2	0%
2014	ND	0	ND	0	0	0	40	45.2	0%
2015	ND	0	ND	0	0	0	35	41.2	0%
2016	2.7	2.8	ND	0	0	5.5	40	52.7	11%
2017	1.5	2.2	ND	0	0	3.7	39	51.8	7%
2018	1.6	3.9	ND	0	0	5.6	32	45.8	12%
2019	2.4	4.8	ND	0.4	0	7.5	ND	12.7	ND
2020	2.2	3.6	ND	0.6	0	6.4	ND	ND	ND

Note: ND indicates need for data. Data should be viewed as incomplete and subject to change with additional data. Data for Virginia are estimated from Figure 2 in the Virginia Shellfish Aquaculture Situation and Outlook Report (Hudson 2019). Data for Louisiana were reported in meat pounds for 2018 and 2019 (with values of $130,039 and $55,728, respectively) with all other years listed as confidential due to privacy concerns with limited harvest.

Sea Grant Consortium (MASGC) funded a 2010 research project through Auburn University, in partnership with industry member Point aux Pins, titled "Oyster farming in Alabama: Identifying most viable practices." This study experimentally compared how four different culture methods affected oyster survival, growth, and quality. Of these, three methods (suspended adjustable long lines, floating cages, and floating bags), were demonstrated to control bio-fouling through periodic desiccation, while also producing high yields of quality oysters (Walton et al. 2013b). Critically, this work led to media attention for the industry partner, which in turn led to other stakeholders expressing interest in learning more about off-bottom oyster farming.

Demonstration, Education, and Hands-on Training

In response to this new interest, Auburn University and Louisiana State University pursued, and were awarded in 2010, a National Sea Grant Extension award titled, "Aquaculture Extension NSI 2010 - Farming the Fertile Crescent: Intensification of Oyster Culture in the Northern Gulf of Mexico." This bi-state effort supported site selection, permitting of demonstration farms and 'oyster farming parks,' and training programs for potential oyster farmers. In Alabama, the training course was offered in partnership with the Organized Seafood Association of Alabama, which was critical to successful recruitment of the first class. The training course offered in Alabama was a 15-hour series of informal lectures and demonstrations, capped by each of the trainees raising at least 10,000 oyster seed in the demonstration area to gain valuable hands-on experience prior to starting their own commercial operations.

This three-year effort resulted in five measurable outcomes.

1. In Alabama, an oyster farming park was permitted that includes twelve 2-acre farm sites for commercial production and another seven 2-acre sites were permitted by the Grand Isle Port Commission, for a total of 38 acres permitted for commercial production;
2. A commercial demonstration site was established in both Alabama and Louisiana, serving as hands-on exposure for potential oyster farmers;
3. By the end of the grant, five individuals

had begun commercial production with an additional six initiating the permitting process (with permitting challenges identified as a barrier to growth);
4. Nine individuals participated in the Oyster Farming Fundamentals training program with dozens of other individuals getting exposure to this new industry; and
5. At least 20 stories were generated in the media, including local television and national radio (NPR), with thousands of individuals increasing their awareness of the availability of off-bottom farm-raised oysters.

Addressing Production Challenges

In a series of research grants, several academic institutions partnered with the new commercial oyster farmers to address challenges to production. In 2010, Louisiana State University led a National Sea Grant funded study, "Evaluation of oyster stocks and grow-out methodologies for commercial production of Eastern oysters in Gulf of Mexico estuaries" to determine if different stocks performed better for oyster farmers. The results suggested that selective breeding has the potential to improve survival and growth though the benefits may be site-specific (Casas et al. 2017).

Researchers from Dauphin Island Sea Lab, funded by the MASGC in 2016, responded to concerns by growers about how to manage mud blister worm infestations of their crop with a research project titled, "Maximizing the return on investment of oyster aquaculture by managing mud blister worm infestation." Mud blister worms blemish the oyster shells which some growers were concerned about in terms of perceptions of product quality. Researchers identified times of year where farmers need to exercise extra control methods to avoid infestation (Cole et al. 2020; Dorgan et al. 2021).

Similarly, with some growers reporting high mortalities of triploid oysters in 2016, researchers sought to respond. In 2018, National Sea Grant awarded researchers at Louisiana State University a grant titled, "Decreasing mortalities of triploid eastern oysters in commercial grow-out in Gulf of Mexico estuaries." As with the mud blister work, this applied research was driven by explicit concerns from commercial oyster farmers. This work is in progress, but preliminary results have suggested that initial attempts at selective breeding to reduce these losses were not fruitful. Researchers are seeking to identify what steps might be taken to address this problem (Wadsworth et al. 2019; Bodenstein et al. 2021).

Addressing Regulatory Challenges

Beyond challenges to production, Sea Grant played a critical role in addressing regulatory concerns with timely, focused research and an ongoing role facilitating communication among stakeholders. In Alabama, permitting fees for riparian easements initially exceeded $6,000/acre/year, as shellfish farms were equated with private marinas; these fees discouraged investment. With a 2012 National Sea Grant award to Auburn University and the National Sea Grant Law Center ("Economic value of ecosystem services of oyster farming as offsets to regulatory fees"), research was conducted to provide regulators better information about the value of oyster farming. During the course of this work, the fees dropped to $250/acre/year, prompted by the dialogue among stakeholders about the public benefits of oyster farming (Walton, pers. obs.).

In Alabama, public health concerns caught the industry off-guard with regulatory requirements to submerge their oysters for 30 days prior to harvest (Walton, pers. obs.). This was later reduced to 14 days, but many growers were concerned about the effect of this required resubmersion on their operations. The MASGC funded "Effects of aquaculture practices on *Vibrio* spp. in the Eastern oyster, *Crassostrea virginica*: Test of fouling control practices" with an award to Auburn University in 2014. This research directly led to a reduction to seven days of resubmersion for certain culture methods in Alabama and has been used to guide practices in other states around the U.S. (Grodeska et al. 2017; Grodeska et al. 2019).

Addressing Marketing Challenges

One of the main challenges to industry expansion was the fear that consumers would not be willing to pay enough for oysters from the Gulf of Mexico. This was compounded by perceptions by some consumers about risks associated with consuming raw oysters from the region. To provide existing

and potential growers a better sense of market perceptions and willingness to pay, the MASGC funded a research project led by Mississippi State University titled, "National survey of consumer preferences for branded Gulf oysters and risk perceptions of Gulf seafood." While there were some differences among regions, the study found that consumers' willingness to pay was sufficient to support off-bottom oyster farming in the region (Petrolia et al. 2017).

To help seafood servers increase sales of farm-raised oysters, Sea Grant also partnered with the Auburn University Shellfish Lab to develop and provide 'Oyster Essentials,' a short training program intended to increase knowledge of farm-raised oysters. Chefs and distributors have provided very positive feedback, with qualitative descriptions of increased oyster sales (Walton, unpub. data).

Sharing Knowledge and Building Community

In addition to applied research, Sea Grant's efforts stand out for the investments into peer-to-peer learning and community building, which have been critical building blocks in the growth of off-bottom oyster farming in the region. In the first years, knowledge exchange among states was coordinated through Sea Grant agents, including grower workshops and farm site visits.

More formally, National Sea Grant supported the Oyster South Symposium with an award to Auburn University in 2016, "Sea Grant symposium for OysterSouth: A submission to the 2016 aquaculture Sea Grant conferences and workshops competition." This funding allowed growers to both attend and present at this industry-focused meeting. National Sea Grant, seeing value in this exchange of knowledge, provided additional funding to Auburn University in 2017 ("Enhancing Peer-to-Peer Learning Opportunities for Southern Oyster Farmers") to allow oyster farmers to visit other oyster farms around the country and world, as well as attend industry symposia. Though difficult to quantify, many growers throughout the region regularly note that the community around Oyster South, a 501(c)(3) dedicated to advancing oyster aquaculture in the southern U.S., has been a boon to the growth of the industry. The Oyster South community (growers, distributors, chefs, media writers, etc., all sharing an interest in southern oyster farming) has further networked Sea Grant agents and Extension specialists across the region as a common platform. Specialists regularly shared information and resources, working together on workshops and products.

Responding to Disasters

Finally, Sea Grant has played a critical role in responding to disasters that have affected this new industry, including the Deepwater Horizon Oil Spill, hurricanes, harmful algal blooms (e.g., Sempier et al. 2019), and the Covid-19 pandemic. Disasters often demand immediate responses that are not suitable for typical request for proposal timelines, but Sea Grant programs adapted and provided the information requested by stakeholders. With hurricanes, Sea Grant has assisted with recovery of gear and coordinated post-storm debriefings to help growers share lessons learned. Recently, several Sea Grant programs in the region collaborated to produce a series of fact sheets to help oyster farmers prepare for tropical storms and hurricanes (Callam et al. 2020; Grice et al. 2020; Sturmer et al. 2020; Walton et al. 2020a; Walton et al. 2020b; Walton et al. 2020c). With the loss of sales in 2020 due to the Covid-19 pandemic, many growers were faced with the challenge of holding oysters that had grown past the desirable market size. In Alabama and Mississippi, the MASGC provided a program that purchased oysters from participating growers to donate to stock enhancement programs. Five other Sea Grant programs in the Northeast and the Gulf of Mexico regions implemented similar programs to buy surplus oysters for restoration.

Beyond the discrete, funded research projects, Sea Grant agents have regularly worked with stakeholders in the region, with the National Sea Grant Law Center responding to multiple requests for information.

Discussion and Conclusions

At its core, off-bottom oyster farming in the Gulf of Mexico is the result of the hard work and ingenuity of numerous individuals. Certainly, a wide array of individuals in academia, regulatory agencies, industry associations, and other groups contributed to the development of this industry.

Could off-bottom oyster farming in the Gulf of Mexico have occurred without the investments made by various Sea Grant programs? Perhaps, but we believe that Sea Grant programs played a critical role in the growth of the industry in this region through the integration of applied research with strategic extension efforts.

The critical nature of the role of the MASGC is perhaps most clear in the initial assessment of feasibility. At the time, there was very scattered interest in off-bottom farming along the U.S. Gulf Coast. The private sector had little motivation to undertake the initial costs of exploring the practicality of off-bottom oyster farming, particularly given the outcomes of earlier attempts in the 1990s. In Alabama, Sea Grant was essential in bringing together a local coastal property owner that had participated in a MASGC oyster gardening program (and had recognized that the site had good growth and survival) with the Auburn University Shellfish Lab. This relationship led to a proposal sent to a competitive research call for proposals from the MASGC. This proposal, testing and comparing the performance of four different production methods, was selected for funding. During and after the study, the PIs engaged stakeholders locally and regionally; at the very least, this active engagement was encouraged by the MASGC. The study also resulted in the establishment of Point aux Pins, the first commercial oyster farm in Alabama, by the cooperating property owner. Without this initial investment, it is not clear that off-bottom farming would be established along the U.S. Gulf Coast.

Were any other Sea Grant investments critical to the growth of the industry in this region? The investment in training and demonstration may not have been critical to the establishment of off-bottom oyster farming but very likely played a strong role in the rate of growth of this industry. Many of the individuals trained went on to establish commercial oyster farms, in many cases launching their farms in the oyster farming parks. In addition, the awareness of this program in Alabama and Louisiana appears to have generated interest in neighboring states. In the case of Florida, a community college instituted a training program inspired at least in part by these Sea Grant training programs and demonstrations (with the leaders of that program having visited the demonstration site in Alabama) and Mississippi explicitly adopted the training program established in Alabama. This training program is currently completing its third class, and a large oyster farming park is permitted near Deer Island (Biloxi, MS). Texas engaged Sea Grant specialists from other states in its initial exploration of off-bottom oyster farming, passed legislation to allow off-bottom oyster farming, and is currently processing applications.

These two investments (one applied research, one extension) are the investments most readily identified as essential to the establishment and growth of the industry. The additional investments, however, should not be discounted as providing benefit to the industry that allowed or enhanced industry growth. Research applied in a timely manner to address important production and marketing questions has provided information useful to industry members. Additionally, research into the value of ecosystem services was associated with a drastic reduction in the easement fees charged by the state of Alabama (from over $6,000/acre/year to $250/acre/year). Research into managing the risk of *Vibrio* spp. through different culture methods was used to improve industry regulations.

What distinguishes Sea Grant's role in this case study and in many other programs? In our assessment, the following characteristics lend themselves to directed, measurable outcomes.

- First, Sea Grant programs have 'boots on the ground' in many coastal communities, with established relationships with stakeholders. This has allowed many Sea Grant agents to build relationships and trust with stakeholders.
- The Sea Grant culture encourages listening to stakeholders' concerns and interests and using this information to guide programmatic investments.
- Many Sea Grant programs include 'relevance' in their reviews of competitive grants after technical reviews, prioritizing technically sufficient proposals based on stakeholder input.
- Sea Grant measures success in terms of outcomes, rather than outputs, focusing on how research is used to change behaviors.

- Finally, Sea Grant programs tend to be nimble and can respond to stakeholder needs in a fashion that produces outcomes in a timely fashion.

This model of investment stands as an example of how applied research and extension efforts can be used to respond to stakeholder concerns and cultivate a new industry. Investments by the MASGC enabled the establishment of commercial off-bottom oyster aquaculture in Alabama and Mississippi, and in turn, through partnerships and collaboration with other Sea Grant programs, Cooperative Extension, and other partners, these investments helped commercial off-bottom oyster aquaculture become established throughout the U.S. Gulf Coast. This case study suggests that a combination of applied research projects, extension projects, and ongoing extension efforts, as exemplified by the MASGC's approach to off-bottom oyster farming, can yield measurable outcomes with significant impacts in communities.

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