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Excessive Freshwater: Expanded Utility of Extension Programming in an Estuarine Environment

Abstract

We explore the utility of extension programming to demonstrate the consequences of environmental changes in our review of the Mississippi Oyster Gardening Program. Rainfall in the study area was not significantly correlated with near shore salinity, however, when including the freshwater discharge from the Bonnet Carre` spillway, we found a strong negative correlation between total freshwater input with near shore salinity. Low salinity and significant mortality reduced the restorative value of the extension effort but underscores an opportunity for stakeholders, exposed to the same impacts of the environmental changes, to become aware and apply adaptive management in near real time.

Introduction

Oysters, and the reefs they develop, are known as exceptional nutrient sinks with filtration rates of 0.12 m^3g^{-1}dry weightday^{-1} among a host of additional ecosystem services (Locher et al., 2021; Newell, 1988; Parker, 2021; van der Schatte Olivier et al., 2020). It is generally accepted that global stocks of oysters have declined from historic levels. Beck et al. (2011) reported that up to 85% of global reef inventory has been lost. This project area lies in the center of one of the few remaining places they identified where restorative efforts can be effective. As such, citizen science monitoring efforts focused on restoration of reef inventory in the northern Gulf of Mexico are useful both as an educational and a restorative strategy. We review the origins, capacity, and economic value of the Mississippi Oyster Gardening Program (MOGP) production and volunteer time. Additionally, we consider the ability of extension programming to generate utility to broader stakeholder communities, above traditional roles, including real time indicators of environmental changes within the operating theater.

The concept of oyster gardening originated with efforts in the Chesapeake Bay region and successful replicates are found throughout the Atlantic and Gulf of Mexico coasts. Oyster gardening, as we define here, involves citizen scientist volunteers ranging in age from elementary to retiree. Participation in MOGP includes hands-on nursery care of juvenile oysters, known as ‘spat’, from summer through fall. The experiential learning environment is derived from the immersive exposure to an oyster’s biology and their larger role in an estuarine ecosystem. At the conclusion of a gardening season, project personnel take harvested oysters to local restoration sites for planting. This restorative element connects the effort of participants to local impacts and highlights opportunities extension programming can have in vulnerable regions. Direct engagement by stakeholders provides near real time awareness of consequences stemming from changing environmental conditions that related commercial and community interests may face.

The Mississippi Oyster Gardening Program (MOGP) began in 2016 as a pilot project structured primary to replicate the successful neighboring Mobile Bay (AL) program. We acknowledge that the methods of delivery presented here represent one of several approaches to volunteer programming, even among shellfish focused efforts. We present the MOGP as a successful, volunteer centric extension program that delivers multi-faceted returns including as an indicator of current, or potential, shellfish performance while simultaneously providing a robust educational delivery tool for estuarine regions.

Methods

Program management logistics

The oyster gardening program in Mississippi purchases and utilizes seasoned, recycled whole oyster shell derived primarily from the oyster shell recycling program in Alabama. Recycled, seasoned shell is washed and graded to ensure they hold within the mesh gardening basket. Personnel count and bag prepared shell in units of 100 to facilitate end of season production calculations. Hatchery spawning of diploid broodstock, using the thermal shock method, occurs in the spring to produce larvae for setting (the process of oyster larvae completing metamorphosis from free-swimming to permanent attachment) the prepared seasoned shell. Once larval oysters complete setting they are referred to as ‘spat’ and the recycled shell, on which they set, as a ‘spat set shell’. MOGP sites receive multiples of 100 spat set shells and provide nursery care during the season in four (4) 25.4 mm square, PVC coated wire mesh baskets. Baskets measure 45.72 cm deep × 35.56 cm wide × 20.32 cm tall and are secured to the gardening pier by a down line. Down line lengths vary among and within sites by pier location with each suspending the gardening basket in the water column at a target of 30 cm above the bottom.

MOGP volunteers and personnel measure shell growth monthly throughout the gardening season. At the conclusion of the season, personnel calculate a mean height from 20 samples haphazardly selected from each site. This represents approximately two percent of individual sites’ historical production. At the conclusion of a season, we record a final mean height for the regional and program wide comparisons. We extrapolate total site counts (production) from 10 haphazardly selected florets (spat set shell following the nursery phase). Personnel use a constant of 100 total florets per site based on the initial spat set shell count made in preparation for spawning. The program adjusts a site’s total production based on the multiples of 100 delivered spat set shell or, in the event of loss during the season, a total direct count of florets at the time of pickup.

Program impact calculations

MOGP, similar to other OGPs, capitalizes on the novelty of growing oysters as a conduit for educational program delivery. Personnel estimate an ecological impact from the total number of oysters produced in a season based on densities of five advanced stocker oysters planted per meter square (mean height 50-75mm). Using Grabowski (2012), who considered the value ecosystem services (habitat value, water quality improvement value, cultural significance, food values, etc.) of restored oyster reefs, personnel estimate an economic impact. We adjust these values for inflation using the consumer price index. We calculate volunteer hour values from published figures by the Do-Good Institute (University of Maryland) and present the estimated value based on the expected 15 hours volunteers will spend providing nursery care during a season. We estimated total economic return from the sum of production and volunteer time value in Table 1.

Table 1. The annual value of restoration, volunteer time, and annual total value by year for the MOGP.

	Dollar Value		
Year	**Planted Oysters**	**Volunteer Time**	**Total**
2016	$1,377.00	$724.20	$2,101.20
2017	$29,715.00	$4,444.20	$34,159.20
2018	$35,986.00	$11,443.50	$47,429.50
2019	$52,083.00	$33,456.00	$85,539.00
2020	$37,002.00	$50,515.80	$87,517.80
2021	$6,686.00	$59,301.00	$65,987.00

Results and Discussion

Production history

Including the pilot program (2016), MOGP has completed six seasons with volunteers actively engaged in hands-on educational and restorative efforts focused on oyster ecology in their local estuarine systems. The program enjoyed rapid growth in volunteers (Figure 1) based on active word of mouth and program recruiting efforts based on Waters et. al (2021) in their national survey of oyster gardening program participants.

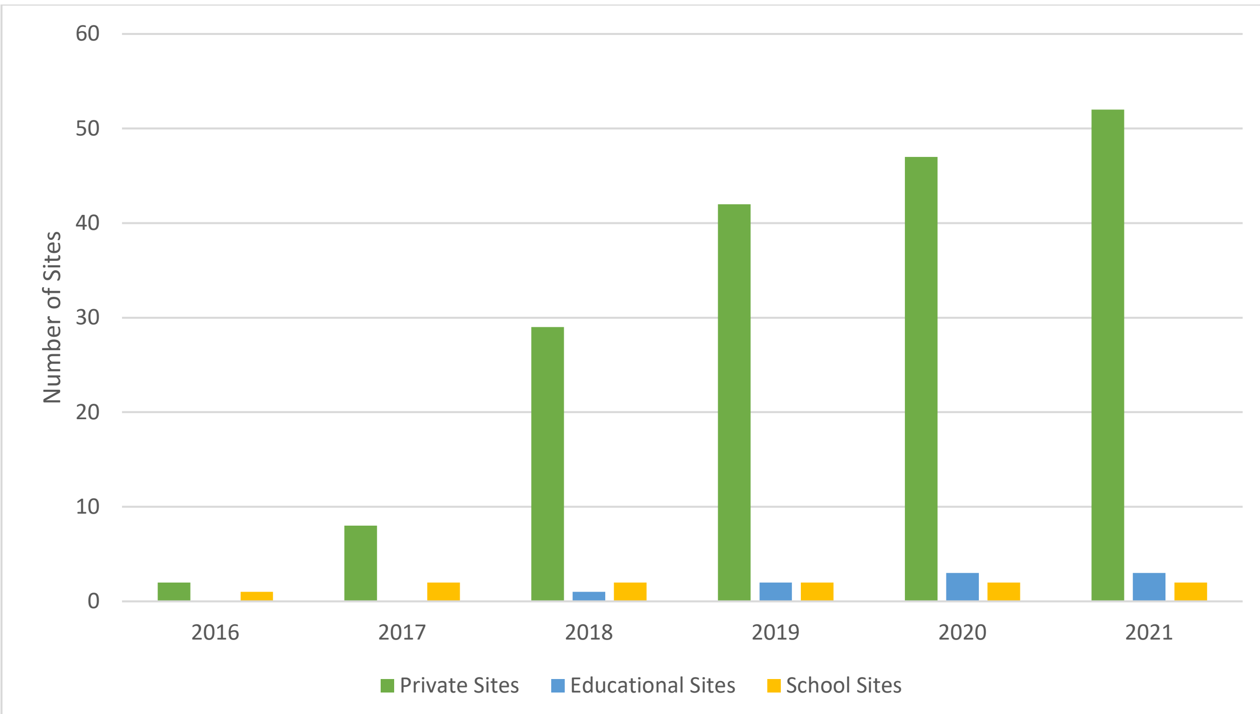

Figure 1. Mississippi oyster gardening program growth and site distribution among classification strata.

Annual production, and associated production value, within this program rose initially, likely a result of growing volunteer numbers, before collapsing over the 2020 and 2021 seasons (Figure 2). We associated this dramatic decline in production with a decline in salinity driven largely by increased freshwater inputs within the local and regional watershed. These freshwater inputs, and the attributed consequences, are the primary threat to the future of shellfish activities, regardless of motivation (commercial, recreational, restorative, or educational).

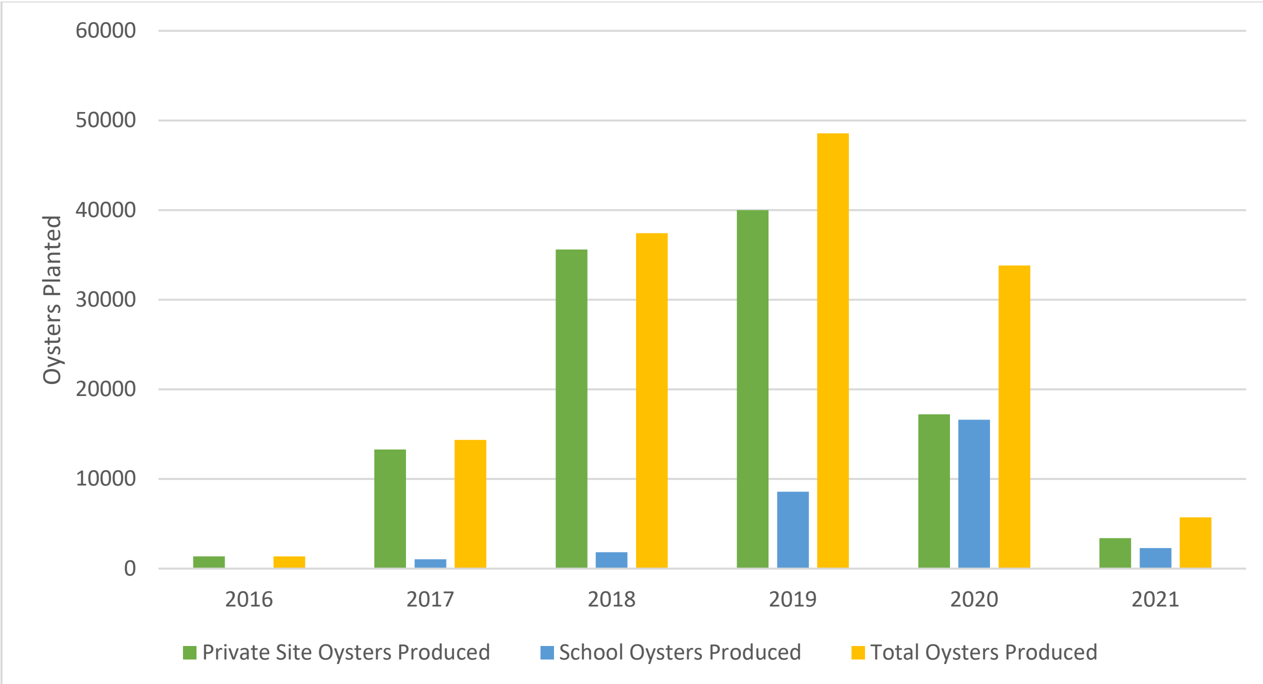

Figure 2. Mississippi oyster gardening production by site classification.

Salinity in coastal Mississippi

Galtsoff (1964) reported a dual zone of preferential salinity which, when linked, yields an overall advantageous range of 5-30ppt. Galtsoff (1964) further describes oysters exposed to conditions below and above this range as existing, but not without costs to their development (growth and reproduction). Powers et al. (2017) described a narrower band of salinities (8-21 ppt) which supports the existence of a minimal salinity level. Evaluation (ANOVA) of the study area’s local, county-based rainfall showed a statistically significant difference in mean annual rainfall among most of the study period years (2016-2021; Figure 3; $P \leq 0.001$).

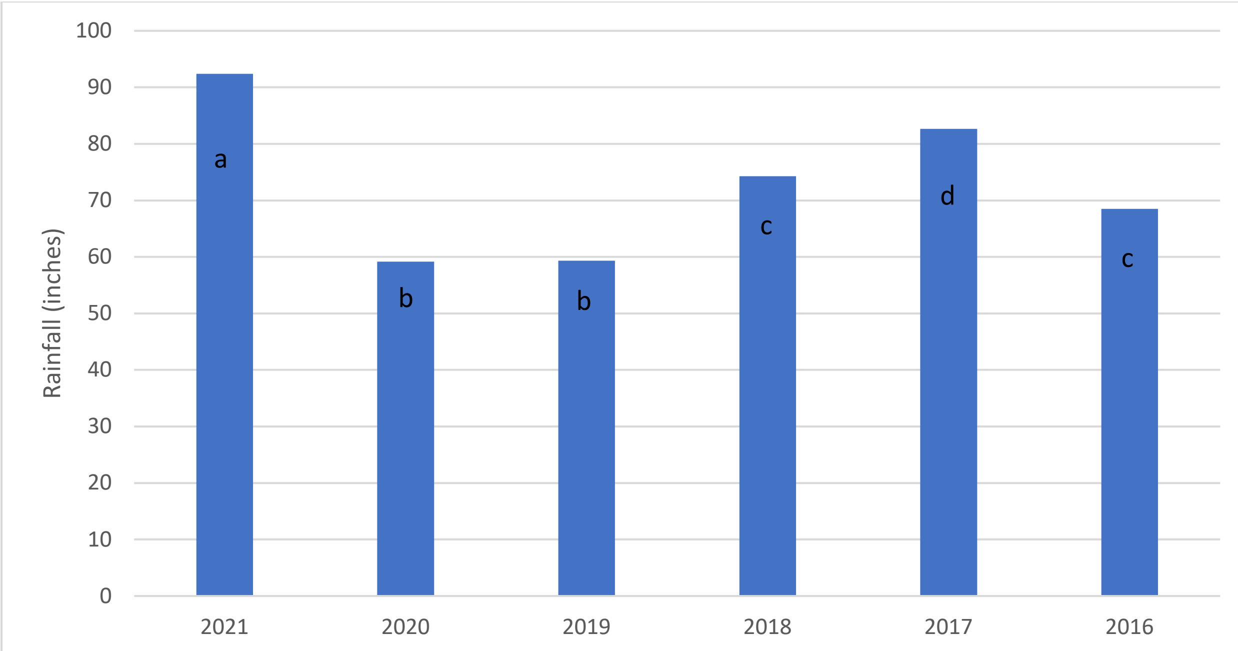

Figure 3. Mean rainfall across the three Mississippi coastal counties. Post Hoc (Tukey's HSD) $P \leq 0.028$.

We considered annual rainfall distribution by subdividing the study period into four-month intervals across all coastal Mississippi counties. Statistical analysis (ANOVA) found significant differences ($P \leq 0.001$) among interval mean rainfalls. Post hoc analysis with a Tukey's HSD correction found statistically significant differences between the May- August period (mean rainfall 21.92 ± 9.72 cm) and both the January-April (13.44 ± 8.07 cm; $P \leq .001$) and September- December (11.35 ± 7.74 cm; $P \leq 0.001$) periods. We found no significant difference between the January- April and the September- December periods ($P = 0.103$).

These findings point to a general trend for coastal Mississippi where the period of May-August receives the majority of the annual rainfall. A comparison (ANOVA) among the periods' mean rainfall within each of the study years generally supported this ($P \leq 0.015$) with the lone exception of 2018 ($P = 0.33$). Post Hoc analysis with a Tukey's HSD correction illustrated the mean rainfall in the May-August period was significantly higher ($P \leq 0.04$) than either of the other periods with the exception of the 2019 May-August to January-April period comparison ($P = 0.085$). These findings supported those trends described by McDonald et al. (2015).

We used precipitation data by county (National Centers for Environmental Information, 2022) combined with area data (Mississippi Water Data Maintainer, 2022) to estimate volume of liquid freshwater input for the interval May-August during the study period year. We calculated mean salinity for the same time period using data from near shore monitoring sites (Mississippi Water Data Maintainer, 2022) recorded every quarter hour. A Pearson Correlation (county area rainfall volume and mean salinity) showed no significant correlation (r (4) = -0.59; $P = 0.214$) between precipitation and salinity for the time period.

In addition to local and regional precipitation, discharge from the Bonnet Carre` spillway has the potential to contribute additional freshwater to the Mississippi Sound from west to east by way of Lake Pontchartrain (LA). Located in St. Charles Parish, the spillway is a flood risk management device capable of diverting 0.25 million ft^3s^{-1} from the river system through Lake Pontchartrain and into the Mississippi Sound. These diversions provide flood protection for the city of New Orleans and the lower Mississippi River Valley region (Roe, 2018). During the six-year study period, the spillway opened five times for a total of 198 days and diverted more than 14.3 trillion additional gallons of freshwater into the sound.

We considered the volume of discharge (Mississippi Water Data Maintainer, 2022) for the same May-August interval in each year of the study period. A Pearson Correlation found a statistically significant, strong negative correlation between total freshwater input (volume precipitation + volume of discharge from the Bonnet Carre` Spillway) and the mean, near shore salinity during the May- August interval (r (4) = .98; $P \leq 0.001$). Total freshwater volume input explained 95.5% of the variation in the mean salinity for the time period. The consequence of the combined rainfall locally and the regional upstream flooding which generated river flow rates at or above the action level and triggering the opening of the Bonnet Carre` Spillway is a likely contributing agent of the reduced salinity within the Mississippi Sound.

To evaluate the impact on oysters in the Mississippi Sound, and the associated ecosystem service value, we considered commercial (Mississippi Department of Marine

Resources, personal communication) commercial landings of wild (natural production, not farmed) oysters for the same time period. We found that the seasons following the 2016-2017 season, wild harvest (sack counts) declined rapidly from 40,165 (2016-2017) to 3,852 (2018- 2019). During this time period, routine salinity monitoring in the study area by MOGP personnel facilitated a decision to delay the start of the gardening season in an effort to avoid the low salinity environment. A casual comparison of commercial to MOGP production over the same period shows an inverse relationship for both 2017- 2018 and 2018-2019, suggesting that the delayed distribution tactics employed by MOGP were effective. The trend reversed for the 2019- 2020 and 2020-2021 seasons where MOGP production collapsed and commercial sack harvests stopped in the same periods, highlighting the limitations of the delay tactics.

During the study period, the spillway opened in 2016 and 2018 - 2020, however only the years of 2019 and 2020 did the openings occur during the May-August interval. This timing aligns well with the expected heaviest period of spawning, settling, and metamorphosis activity in oysters. As a result, we attribute the overall collapse of production from both the wild harvest regions and MOGP sites to a combination of the duration and timing of the spillway openings in 2019 and 2020. While this has obvious implications for the restoration objective of this extension program, it highlights the potential of the educational element. Specifically, participants witness firsthand, through the mortality of their oysters, the consequences of the significant environmental changes we attribute to the added freshwater stemming from the opening of the Bonnet Carre` spillway.

Conclusions

These findings are of particular importance given the seasonality of total significant freshwater input and the spawning activities of wild and hatchery raised oysters along the Mississippi Sound. Commercial interests are impacted by this temporal overlap, including wild catch fisheries and hatcheries drawing source water from the same area. Prior season losses resulted in necessary delays in MOGP activities (spawning and distribution) to hedge against persistent, region-wide low salinity. These steps helped mitigate downside risk to program performance at minimal cost, primarily realized in terms of time (volunteer value) and exposure to hands-on opportunities (extension value) within a given program year. However, previous restoration plantings, wild catch reef resources, and farms, which have an incentive to move seed into the field quickly, assume a comparatively larger risk from these freshwater inputs and resulting prolonged low salinity events that occur when oyster larvae and spat are at vulnerable stages.

These findings suggest the Mississippi Sound is capable of assimilating a wide range of local rainfall during the critical spawning, larval, and early post settlement/metamorphosis period of each year class of oysters. When combined with the excess fresh water discharged from the larger watershed via Bonnet Carre` Spillway, the system appears ill-equipped to retain sufficient salinity necessary to support oyster resources through this sensitive period. This was illustrated by the production loss experienced by stakeholder sites during the study period. While detrimental in the short term to program objectives, citizen science monitoring programs such as oyster gardening, can inform decision makers of the consequences of environmental changes. This study highlighted acute changes and the critical need of alternative strategies to manage excessive freshwater within the Mississippi Sound system. Further, these findings highlight a value realized from extension programming beyond the educational and experiential sphere. The low salinity events during this study period, and in particular the significant losses experienced by the extension program during the 2021 program year, illustrate the utility of volunteer- driven extension programming to shed light on the potential consequences of change in regional environments. In our study, the oyster in the estuary served as the proverbial canary in the coal mine, reflecting when estuarine conditions were such that oyster survival chances are minimal. This serves to not only highlight the change in condition but can serve as a warning to commercial and recreational interests who may find themselves facing similar threats. Moreover, by incorporating a hands-on extension model within sensitive zones, stakeholders become aware of the change in condition and its effects firsthand and in near real-time.

We acknowledge a relatively limited data series of the five-year study period, and we did not consider freshwater precipitation falling directly into the Mississippi Sound in our calculus. However, trends found in the data highlight the need for thoughtful consideration of alternative uses for excessive freshwater on a larger watershed scale to provide requisite flood protection while maintaining a suitable estuarine environment along the Mississippi coast. Without such adaptations, shellfish restoration, commercial farming, and wild harvest will remain at risk.

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