Public Policy for Resilient Oyster Management in the Gulf of Mexico: Managing a Vulnerable Species by Engaging Coastal Stakeholders

by

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Abstract

The eastern oyster (*Crassostrea virginica*) is an important economic, ecological, and cultural species throughout the Northern Gulf of Mexico. Despite its importance, oyster populations have been declining long-term throughout the region due to a multitude of natural and manmade factors, such as extreme weather events, pollution, and overharvest, leading to an estimated minimum 50-85% loss. This is especially true for the Gulf states of Mississippi and Alabama, USA, which were once major oyster producing states that rivaled Texas but are now the lowest producers in the Gulf. Climate change is expected to worsen the effects of natural hazards on oysters, including hurricanes, rising sea surface temperatures, and ocean acidification. Oyster production in the Gulf is vulnerable to these changes; thus, it is important to measure its resiliency, or its ability to absorb shocks and retain essential functions after a hazard occurs. One way to measure and improve resiliency is by engaging with relevant stakeholders, such as oyster producers, resource managers, and researchers, and by analyzing policy and management strategies through theoretical governance frameworks. This research incorporated oyster stakeholders from Mississippi and Alabama, who were engaged via community programming called a community of practice and qualitative research methods such as interviewing and surveying to explore perceptions of industry challenges and therefore identify resilience gaps. Example gaps include long aquaculture permitting times, limited oyster physical and programming infrastructure, and regulatory confusion, among others. However, this research has also identified policy learning related to the oyster industry, indicating that the system has learned from previous hazards and has implemented policies and programs to increase the industry's resilience. These include the implementation of off-bottom oyster aquaculture, oyster shell recycling programs, and cooperative oyster research throughout Gulf states, among others.

Though the system is engaging in learning and identifying new policies, this research indicates that its status is precarious and that the oyster industry may succumb to a series of natural and/or manmade hazards.

Artificial Intelligence (AI) Use Disclosure Statement

In the preparation of this dissertation, no Artificial Intelligence (AI) tools were used.

Acknowledgments

This dissertation is dedicated to all of the people who participated in this research and my family. Without them, this would not have been possible.

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List of Abbreviations

AL	Alabama
ADCNR/AMRD	Alabama Department of Conservation and Natural Resources / Alabama Marine Resources Division
ADPH	Alabama Department of Public Health
CoP	Community of Practice
FL	Florida
FDACS	Florida Department of Agriculture and Consumer Services
LA	Louisiana
LDWF	Louisiana Department of Wildlife and Fisheries
MS	Mississippi
MASGC	Mississippi Alabama Sea Grant Consortium
MDMR	Mississippi Department of Marine Resources
NGO	Non-governmental Organization
TX	Texas
TPWD	Texas Parks and Wildlife Department
U.S./USA	United States of America
USDA	U.S. Department of Agriculture
FDA	U.S. Food and Drug Administration
NMFS	U.S. National Marine Fisheries Service
NOAA	U.S. National Oceanic and Atmospheric Administration

Introduction

The Gulf of Mexico (hereafter, “the Gulf”) oyster population and corresponding industry have played a major role in the region’s culture and economy since the late 19th century (Davis 2017). Unfortunately, despite year to year fluctuations, oysters have been declining in the Gulf over long-term trends (Seavey et al. 2011, Moore et al. 2020, La Peyre et al. 2021). These declines have both manmade and natural origins, such as overharvesting (Beck et al. 2011) and oil spills (Grabowski et al. 2017), as well as hurricanes (Haby et al. 2009), salinity fluctuations (Turner 2006) and predation. These problems are compounding: natural hazards are thought to be increasing in strength and/or frequency in the wake of climate change (Spalding et al. 2014) and are potentially exacerbated by man-made hazards, such as pollution and coastal development, possibly limiting the industry’s resilience[1] and ability to persist into the future.

This dissertation explores the Mississippi and Alabama oyster industries using governance frameworks to identify potential resilience challenges and opportunities. There are four aspects within the industry we examine using qualitative methodologies: 1) community involvement, 2) policy and management, 3) stakeholder perceptions, and 4) climate change impacts and mitigation strategies (Figure 0.1). This research was done in accordance with the Auburn University Institutional Review Board #22-445 EX 2210. Firstly, Chapter 1 will discuss the creation of an oyster community of practice in Alabama and Mississippi, which focuses on communication, collaboration, and trust building across oyster stakeholder groups. Chapter 2 is a five-part comparative case study of the public policy systems to manage oysters in the Gulf of

[1] Defined as the “capacity of a system to absorb recurrent disturbances and retain essential structures, processes, and feedbacks” (Adger et al. 2005)

Mexico states analyzed using the Coastal Governance theoretical framework[2]. Chapter 3 is an in-depth look at the challenges facing numerous sectors of the oyster industry collected via one-on-one interviews and surveys, analyzed using the Adaptive Governance theoretical framework. Finally, Chapter 4 utilizes climate scenarios to communicate how environmental hazards may impact the oyster industry in the future, and how stakeholders may respond to said changes based on available strategies and perceptions. These four chapters examine the socio-ecological systems in the Gulf relating to the oyster industry, and how vulnerable and resilient the industry is to climate change and man-made disasters.

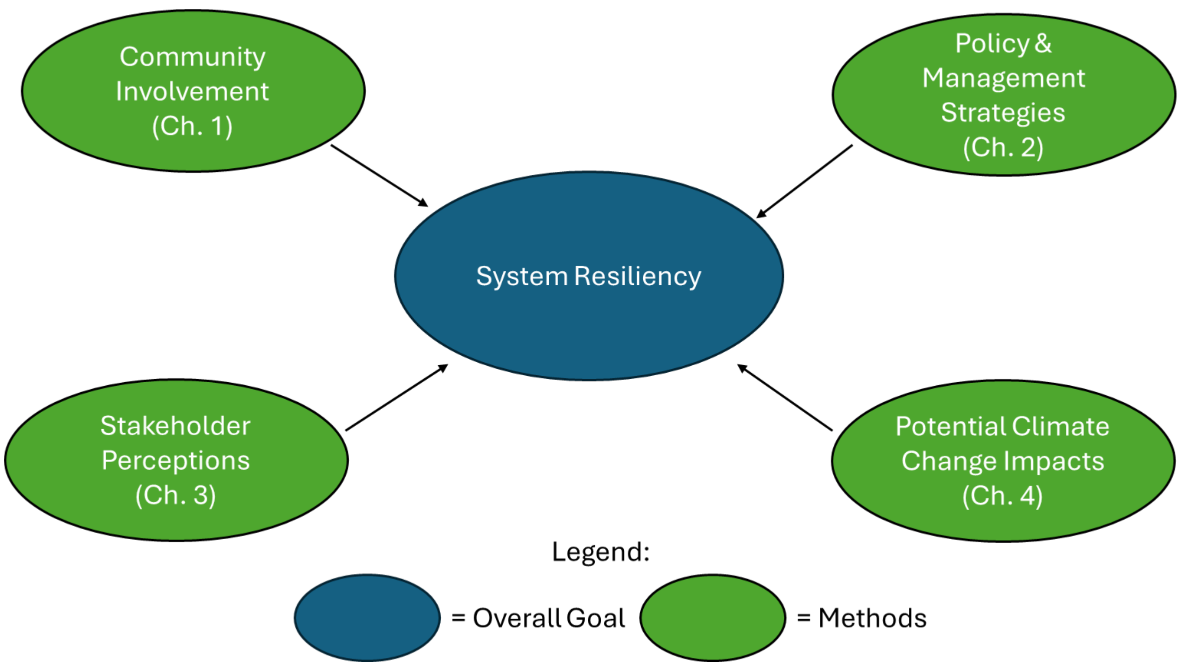


Figure 0.1 A conceptual model of each chapter and the overall goal of this project.

[2] Theoretical frameworks are analysis tools consisting of consistent vocabulary so that phenomena across research studies are explained the same way (Grant and Osanloo 2014)

Chapter 1: Developing a Community of Practice for Greater Stakeholder Engagement: A Case Study of the Alabama and Mississippi Oyster Industry

Abstract

The community of practice concept is an emerging approach in natural resources management designed to increase interactions between stakeholders and may be particularly useful where mistrust and contention exist. Specifically, this practice offers opportunities for improved communication, knowledge sharing, and trust building between groups, with the potential of enhanced collaboration on resource issues. On May 13th, 2023, 54 stakeholders from the Alabama and Mississippi oyster industry met as a community of practice to discuss challenges in the industry in the northern Gulf of Mexico. Discussions from these groups were then used to guide four other community meetings throughout 2023-24. We believe these meetings have provided constructive platforms for enhanced communication over regulation misconceptions, knowledge sharing relating to mitigation strategies for oyster mortality, and trust building between resource managers and users in the oyster industry. Findings are of interest to those working on natural resource issues that could benefit from focused, collaborative exchanges using the community of practice method.

1.1 Introduction

Determining and incorporating stakeholder perceptions is important for effective natural resources management as different groups rely on these resources for economic and environmental reasons and thus may have different priorities for management outcomes (Kingsley-Smith et al. 2015; La Peyre et al. 2012). One method to engage stakeholders, collect shared perceptions on management needs, increase communication, share knowledge, build trust, and create collectively defined management goals is by developing a *community of practice*. A community of practice (CoP) is a group of stakeholders that regularly meet together to share knowledge about a topic of interest, collectively strategize on improved management, and develop a shared repertoire of resources and tools to address recurring problems (Pyrko, Dörfler, and Eden 2017; Wenger 2011; Wenger and Snyder 2000). CoPs are beneficial and have been implemented in many fields, including business, healthcare, and education. These meetings can allow people to create deeper connections among different stakeholder groups, as well as share knowledge and skills and identify where information and/or resources are needed around a topic for problem-solving (Pyrko, Dörfler, and Eden 2017; Wenger 2011).

Studies of communities of practice in fisheries or natural resource management appear to be under-represented in the literature, though a few examples have demonstrated positive interactions. Whitmore and Safford (2020) identified an organically formed community of practice among oyster farmers in New Hampshire. This group was able to communicate effectively amongst themselves to address challenges in an emerging industry as well as agreeing to self-regulate to keep oyster quality high and discourage opportunistic behavior among other farmers that could threaten the resource. On a larger scale, Álvarez Torres et al. (2017) characterized a scientific community of practice regarding the Gulf of Mexico Large Marine Ecosystem to increase collaboration for ecosystem resiliency and sustainability among three different countries. Based on these successful examples, which highlight increased collaboration and communication among involved parties, a small group of stakeholder representatives endeavored to create a similar group in Alabama and Mississippi to address issues related to the oyster industry.

The eastern oyster (*Crassostrea virginica*) is an important species to the people of the Gulf of Mexico (hereafter, "the Gulf"). Oysters provide significant inputs for local livelihoods via commercial harvest, aquaculture cultivation, seafood processing, and seafood restaurants. Landings from the Gulf alone totaled 12.5 million pounds in 2019, 45% of the nation's total (NMFS 2021). Historically, indigenous people of North America have harvested oysters for millennia (Davis 2017; Reeder-Myers et al. 2022), while more recently, generations of families have built businesses based on the oyster industry, creating a strong cultural connection to the species (Coleman 2003). Oysters also provide numerous ecosystem services, defined as benefits that humans derive from the normal functioning of an organism or habitat, such as water filtration, shoreline protection, habitat for other aquatic species, and carbon sequestration, among others (Grabowski and Peterson 2007). Because of these services, oysters are considered a keystone species[3] and an ecosystem engineer[4]. Despite their importance, oysters are declining in the Gulf, putting the local way of life and important ecosystem services at risk. It is this decline, and the human interest in oysters shared amongst many diverse stakeholder groups that compelled the formation of our CoP.

Oyster numbers have been decreasing in the Gulf over recent decades due to a variety of natural and anthropocentric factors. Many natural stressors impacting oysters come from climate change, such as rising water temperatures and fluctuations in salinities due to increased flooding from storms (Gledhill et al. 2020). Anthropocentric stressors include historical overharvesting, pollution, and coastal construction and alteration (Beck et al. 2009). The combination of these

[3] A keystone species is a species that other species within an ecosystem depend on. If removed, the ecosystem would drastically change.

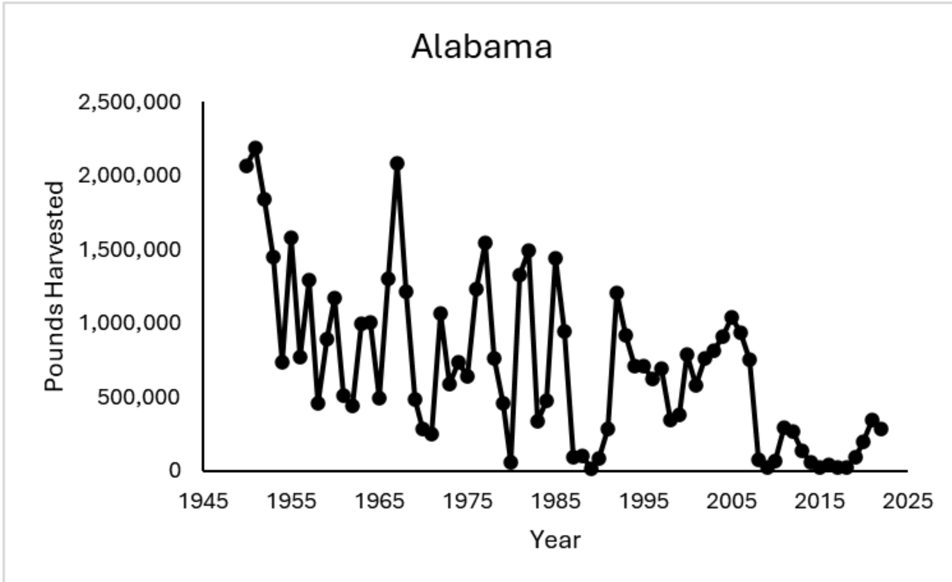
[4] An ecosystem engineer is any species that creates or modifies a habitat.

issues has caused massive (>85%) losses of oyster reefs worldwide over the past century (Beck et al. 2011), and a minimum of 64% loss in the United States (zu Ermgassen et al. 2012).

The CoP described in this study focuses on the Gulf states of Alabama and Mississippi. Historically, these states produced large quantities of oysters each year - hundreds of thousands of pounds of meat[5] worth millions of dollars (Gregalis, Powers, and Heck 2008; Lee 2023). Biloxi, Mississippi, was even once known as the “seafood capital of the world” (Nuwer 2006), but due to major overharvesting over the past century, as well as numerous natural and anthropogenic disasters, both states have suffered major losses in their natural populations (Figure 1.1). For instance, Alabama experienced multiple years of little to no harvest from 2015-2019, though they have been able to harvest approximately 44,000-50,000 sacks[6] of oysters in its two most recent harvest seasons (ADCNR 2023). Further, Mississippi, Louisiana, and Alabama recently experienced catastrophic losses to their oyster populations due to a massive freshwater influx in 2019 that resulted in 100% mortality on Mississippi historical oyster reefs (Gledhill et al. 2020). Mississippi wild harvest was closed from 2019-2024 as a result (Lee 2023, MDMR 2024).

[5] Meat refers to the oyster body without the shell.

[6] A sack contains approximately 30 pounds of adult oysters, including the shell.



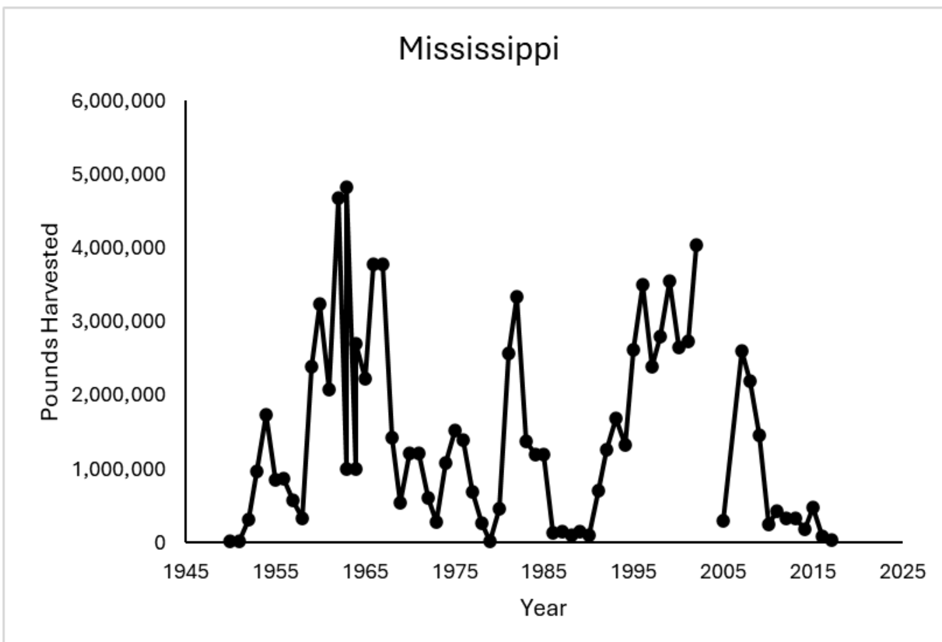


Figure 1.1: Annual commercial landings from Alabama (top) and Mississippi (bottom) from 1950-2022. Data are from the NOAA commercial landings website (NOAA 2023).

The CoP was composed of stakeholders from numerous sectors of the oyster industry from both Alabama and Mississippi, initiating a collaborative effort to exchange information, address challenges directly and generate solutions for future change and improvements to the oyster industry. Our case study is relevant to other contexts, where natural resources are facing persistent or catastrophic declines, necessitating urgent shifts in management, and engagement between stakeholders and resource managers.

One of the key goals of the CoP was to facilitate communication, knowledge sharing, and trust-building between stakeholder groups. Leading up to the formation of the CoP, interactions between oyster resource users and resource managers were filled with tension and frustration. Based on key informant interviews with stakeholders, tensions were due to perceived one-way communication that was sometimes inconsistent and/or distrustful between resource users and managers. Based on other CoPs organized by the Mississippi-Alabama Sea Grant Consortium, successful communication between groups has been demonstrated in the past (MASGC 2024), and we believed that our CoP model would provide an inclusive platform for constructive, multi-way communication among oyster stakeholders. We provided an open space for our participants to share their concerns relating to the industry and discovered numerous challenges to be addressed. Here, we report on the initiation of the CoP, results from the initial and subsequent meetings, important obstacles related to the oyster industry in Alabama and Mississippi, and how the CoP can be utilized here and in other scenarios to resolve contentious natural resource issues.

1.2 Methods

Starting in March 2023, stakeholders from each sector of the oyster community (e.g. commercial and recreational wild harvesters, aquaculture farmers, academics, non-governmental organization leaders, seafood processors and restaurateurs, and government agency officials) were invited to attend the first CoP meeting to ensure that a variety of perspectives could be represented. Invites to and information about the meeting were posted on widely used social media pages focused on oysters, as well as directly emailed to registered aquaculture permit holders from the states of Mississippi and Alabama. Direct invitations were sent to the Alabama

Department of Conservation and Natural Resources Marine Resources Division (AMRD), the Alabama Department of Public Health (ADPH), and the Mississippi Department of Marine Resources. Each of these organizations regulates oyster harvest, aquaculture permitting, and distribution to ensure public health safety. Relevant organizations like Mississippi-Alabama Sea Grant Consortium and the Alabama Cooperative Extension System also publicized the event through their personal and professional social media pages.

The initial meeting was convened on Saturday, May 13th, 2023, in Bayou La Batre, Alabama. Bayou La Batre is considered to be the "seafood capital" of Alabama, with many prospective participants living in and around this area. The meeting took place from 9 am - 12 pm, and nominal financial assistance was provided to assist participants to offset any travel costs they may have incurred to attend.

The meeting described here was the first in a series of quarterly events designed to increase communication and collaboration in the community and was based on previous Mississippi-Alabama Sea Grant Consortium programs. The goal of this initial meeting was to engage participants and gather perceptions on their experiences with current challenges in the oyster industry. Prior to the meeting, the authors conducted conversations with experts in oyster research and management and chose three key topics faced by the Gulf oyster industry to guide conversations: oyster mortality, management regulations, and food quality/water safety.

The meeting adopted a focus group methodology, where participants sat, unassigned, at six tables, each with a facilitator and note taker. Hereafter, each table represented a focus group. Participants spent the majority of the meeting time discussing their perceptions on the three topics listed above as an open conversation guided by the facilitators. Participants were also asked to propose solutions for issues, as well as bring forward new issues of concern that they would like to discuss at future meetings. Note takers documented the topics of each conversation for future analysis. Recording devices, though helpful for verbatim transcription, were deemed to be inappropriate for a first meeting that necessitated trust building (Adams and Cox 2008). The focus groups were conducted in compliance with all ethics as required by Auburn University's Institutional Review Board (#22-445 EX 2210).

After the meeting, notes were collected, consolidated, and later analyzed using a descriptive coding method that uses nouns to summarize the topic of a discussion (Saldaña 2020). Once discussions were summarized into overarching themes, they were quantified to determine the frequency of each concern within each of the three initial meeting topics mentioned earlier as a proxy for relative level of importance. These topics were then used to identify areas of needed improvement that generally fit into three categories: communication, knowledge sharing, and trust building. These topics often became focus matters between stakeholder groups at future meetings (Figure 1.2), as reported below.

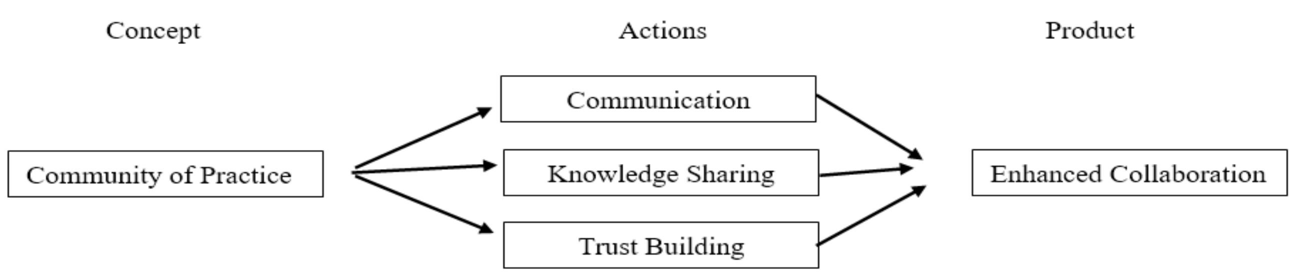


Figure 1.2: The Community of Practice Model for Increased Natural Resources Collaboration.

1.3 Results

Fifty-four participants spanning multiple stakeholder groups participated in the meeting. These included, but are not limited to, aquaculture farmers, non-governmental organization representatives, oyster researchers, hatchery managers and technicians, outreach specialists, resource managers, and seafood processors. The composition of individual focus groups varied, though each focus group contained a minimum of one oyster researcher and one oyster farmer and were of consistent size, about 8 people.

The CoP process was designed to facilitate communication, increase knowledge sharing, and enhance trust building among oyster stakeholders. We theorized that these three features of our model CoP (Figure 1.2) would lead to enhanced collaboration in a relatively contentious industry. The following results are presented so that the framework for our CoP emphasizing communication, knowledge sharing, and trust building can be of general interest to people looking to enact a CoP in other contexts.

The results detailed below highlight challenges and guided content for subsequent CoP meetings in 2023-2024 (Table 1.1) and efforts to build knowledge, trust, and relationships among participants, and enhance collaboration among stakeholder groups.

Table 1.1: The location, date, and topic list of all Alabama-Mississippi Oyster Community of Practice meetings throughout 2023-2024.

Meeting #	Location	Date	Topics
1	Bayou La Batre, AL	05/2023	Oyster mortality, regulations, and water quality/food safety
2	Bayou La Batre, AL, and Virtual via Zoom	08/2023	Alabama state agency regulations
3	Virtual	11/2023	Oyster crop insurance; oyster gardening
4	Biloxi, MS	05/2024	Symposium of local oyster research; Mississippi oyster farming
5	Virtual	11/2024	Oyster crop insurance; Mississippi on

			bottom aquaculture

1.3.1 Improving Communication

1.3.1.1 Major Concerns

Increased communication from important state regulatory agencies was a major point of concern at the first CoP meeting. Participants, especially Alabama oyster farmers, shared their experiences with the ADPH. Perceptions towards this agency were largely negative, as farmers believed ADPH were often unclear about regulation changes and water closures. Water closures occur during high bacteria counts (such as fecal coliforms) or if there is excessive flooding from freshwater sources, making oyster harvest illegal until conditions are normal again to prevent foodborne illness (Ala. Admin. Code § 420-3-18). One farmer shared that they had been uninformed about a water closure and had harvested their oysters, only to be turned away by a seafood processor when they went to sell. This farmer lost time and suffered financial losses due to communication issues, and another farmer expressed that they felt the closures to be "arbitrary."

Other communication issues came to light after participants shared that they felt that state agencies did not communicate when regulations change or why. This frustration was focused on the time to temperature regulations in Alabama, in which farmers have a set amount of time from harvest to put their oysters in mechanized refrigeration. According to participants, ADPH recently changed this regulation at the time of the first meeting, and farmers had shorter timeframes to cool their oysters in summer months. Participants shared that this made harvesting more difficult, especially for farmers who have their operations farther from shore. They now had less time to actually harvest oysters and had to spend more time and resources transporting oysters. Farmers also expressed that they received little to no communication about why this regulation was changed. One participant was recorded as stating, "Regulations are necessarily vague to be flexible," but it is apparent that farmers would like more communication regarding these regulations and how to interpret them.

Finally, participants shared that there have been conflicts between oyster farmers and other coastal resource users due to poor communication. For example, one participant discussed how they believe that some coastal property owners and boaters have negative perceptions towards oyster farms, stating "Coastal property owners want pretty views, not a working coast." Similarly, another participant expressed "People love oysters but don't want to see us fishing for them." However, oyster farms are a sustainable method to produce oysters and can provide many of the same beneficial ecosystem services as natural oyster reefs do, and oyster farmers felt that other coastal resource users and groups were unaware of these benefits due to a lack of communication.

1.3.1.2 Addressed Concerns

The CoP was able to provide a platform to address some of these communication issues in subsequent meetings, especially between farmers and the ADPH. Representatives from the ADPH and the Alabama Marine Resources Division were asked to attend the second CoP meeting, held in August of 2023 in Bayou La Batre, AL, and address concerns brought up at the first CoP meeting and from interactions between the same groups outside the CoP. At the second CoP meeting, speakers from each agency reviewed key regulations for oyster aquaculture and why they exist, and what role each agency has in dictating or enforcing each regulation. This meeting expanded communication between agencies and farmers, and the farmers were able to get answers regarding their questions relating to different regulations.

1.3.2 Knowledge Sharing

1.3.2.1 Major Concerns

The second part of our model is that stakeholders view the CoP as a venue to share knowledge, of which causes and concerns over oyster mortality was the main type of knowledge shared. Farmers mainly shared environmental mortality causes, including low dissolved oxygen concentrations, salinity and temperature fluctuations, and turbidity in the water column. According to one participant, “Most farmers have had huge mortality because of low salinity [events].” Shared knowledge between farmers included techniques to try to mitigate these problems, such as raising gear higher in the water column as low dissolved oxygen is more prevalent along the benthic zone. However, as many of these causes are environmental, they are likely inescapable given oyster aquaculture’s close production ties to its environmental surroundings. This was expressed from one participant, who stated “You can measure water quality, but what do we do?” Thus, sharing knowledge on how to avoid or mitigate for mortality events caused by environmental stressors was deemed to be an important goal for future CoP meetings.

1.3.2.2 Addressed Concerns

One outcome that emerged from discussions and shared knowledge to help mitigate oyster mortality events was for farmers to purchase crop insurance and/or to register for disaster relief funds. Oyster crop insurance is currently available through the United States Department of Agriculture (USDA) Shellfish Crop Insurance Program (USDA 2024). Qualifying farmers can purchase this insurance through private insurance agents. In order to share knowledge about this program, representatives from two private insurance agencies were invited to present at two subsequent CoP meetings (meetings 3 and 5). At these meetings, insurance agents discussed insurance coverage options, application processes and necessities, and other related information.

Through crop insurance, farmers can gain compensation related to the potential market value of oysters lost during specific mortality events. While this program has its challenges, according to CoP participants, it can be a valuable tool for farmers attempting to keep production going after mortality events.

The shared knowledge from the CoP also guided farmers on how they can monitor water quality on their farms. At the fourth CoP meeting, held in May 2024, local researchers were invited to present about different techniques that farmers could use to measure various water parameters, including dissolved oxygen, salinity, and pH. In this presentation, farmers were further informed about cost effective tools they could use to collect data on these parameters themselves. This type of knowledge is important for farmers to know, because if they can keep track of water quality at their farms, then they may be able to predict and better anticipate and prepare for mortality-causing conditions, increasing the sustainability of their farms.

1.3.3 Building Trust among Participants

1.3.3.1 Major Concerns

The third part of our framework for implementing the CoP was enhancing trust between different stakeholder groups in the oyster community. Perceptions of stakeholders shared at the initial CoP meeting suggested a prevailing lack of trust between oyster farmers and state agency specialists based in government. This lack of trust begins with the communications issues previously described, but also has complex causes that can be social, political, and/or cultural. For example, a participant at the initial CoP meeting expressed discontent with regulatory involvement in the aquaculture permitting process, stating “It’s very hard to start a farm with all of the people and organizations that have to sign off.” The CoP was intended to ease these tensions and restore trust, primarily by enhancing face to face contact between oyster farmers and agency staff. This form of trust is necessary for effective management and regulation of the resource (Coleman and Stern 2018).

1.3.3.2 Addressed Concerns

Increased interactions between groups have been shown to help improve trust among them (Coleman and Stern 2018). Representatives from Alabama and/or Mississippi state agencies attended each of the five meetings, and presented at three of the five meetings (meetings 2, 4, and 5). These personnel were also on hand to meet with farmers and oyster stakeholders and answer questions they may have. Thus, it is likely that the CoP improved trust between groups at some level by providing a constructive, neutral space for these groups to interact that they would not have had otherwise. Further, in this constructive space, CoP participants, especially farmers, were allowed to voice concerns and frustrations about industry challenges, such as regulations, accountability for degraded water quality, and issues with poaching directly to state agency specialists. By being able to directly communicate these concerns, participants likely felt heard and validated, leading to increased trust (Coleman and Stern 2018).

1.4 Discussion

Within the three-part framework for the CoP, our emphasis on communication, knowledge sharing, and trust building encompassed many of the challenges raised by stakeholders during the CoP. The types of challenges addressed here are well-documented in the scientific literature, both for the oyster resources and other natural resources (for oyster specific challenges, see May 1973; Lenihan and Peterson 1998; Park, Kim, and Schroeder 2007; Beck et al. 2009 & 2011; Grice and Walton 2017; Sonak et al. 2018; Coogan, Dzwonkowski, and Lehrter 2019; Gledhill et al. 2020). Community groups such as the CoP can help counteract these issues by starting conversations between groups to share knowledge as well as brainstorm solutions. Community groups could also have a stronger voice and be able to reach decision-makers more effectively than individuals (Meyer and Baumann 2022). Additionally, participants in our CoP demonstrated and shared high levels of local ecological knowledge which included expansive understanding of scientific data. This suggests that CoPs can also work as collection points for local ecological knowledge, which could be used to help guide conversations with decision makers (Dunning 2021) (Figure 1.3).

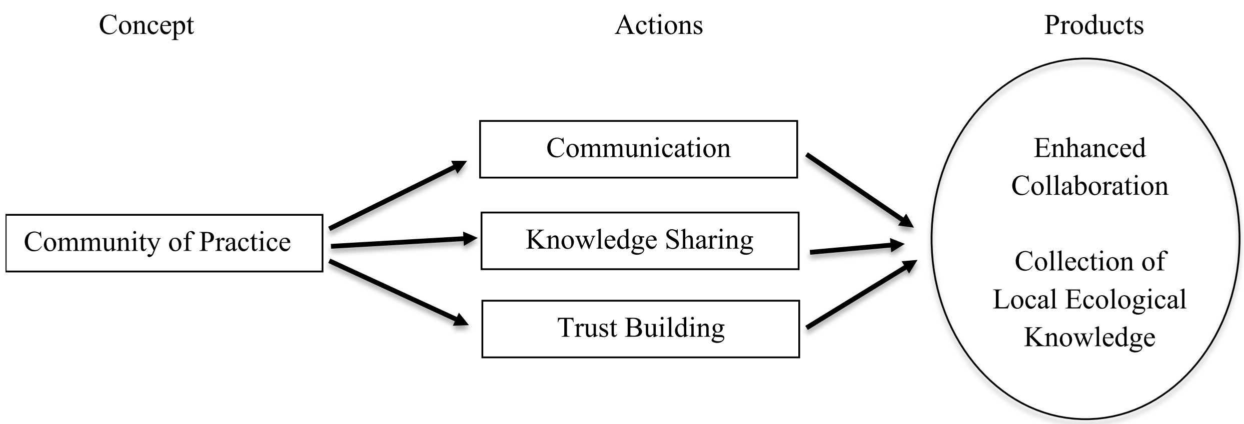


Figure 1.3: The Community of Practice Model for Increased Natural Resources Collaboration with local ecological knowledge as an additional product.

Lack of trust between farmers and applicable state agencies was highlighted as an important challenge to the oyster industry by the CoP. Discontent between public and state entities has been shown to occur in many states in the Gulf (see Erdenesanaa 2022; Lee 2023; Schleifstein 2023) and is possibly part of a larger pattern of general distrust or discontent between the American public and their government (Levi and Stoker 2000; Dalton 2005; Manfredo et al. 2017). Since this first meeting, the ADPH has become more involved and active in events held by the CoP and other coastal organizations, such as the Mississippi-Alabama Sea Grant Consortium. This suggests that CoPs can result in changes in relationships between stakeholders and regulatory agencies once communication is opened and expectations are discussed in these types of venues.

One important thing to note is that the CoP is not a governing body. Though participants may have requests and desires for regulations changes or have beneficial, logical solutions to many problems facing the oyster industry in Mississippi and Alabama, the group lacks the funds and mandate necessary to enact said solutions or make immediate changes. Participants may only be able to communicate the need and ideas for solutions to state government officials and hope that they are listened to. However, the CoP may act as a united platform with the inclusion of state agency officials to help increase communication and increase responsiveness across numerous and power-holding groups.

1.4.1 Expanding the use of the Community of Practice concept

Through this demonstration of the Alabama-Mississippi Oyster CoP, we hope to increase awareness of the CoP concept to others in natural resources management settings. Because of the concept's broad definitions, where a CoP is a group of people who meet to share knowledge about a given topic and that formation can happen organically, people may not even realize they participate in a CoP (Wenger and Snyder 2000). There are documented benefits to establishing CoPs, from trust building, increased collaboration, and facilitating needed discussions (Álvarez Torres et al. 2017; Whitmore and Safford 2020). Additional benefits may include gathering and communicating local ecological knowledge, which may assist with decision making (Dunning 2021). As stated previously, details regarding communities of practice in natural resources settings are limited in peer-reviewed literature. Increasing awareness about CoP in the literature could help establish this concept in more natural resources settings, improve recognition and communication about its application, and eventually increase the trust between resource users, managers, and regulators.

Previous descriptions of the CoP concept characterize it as an informal (Wenger and Snyder 2000), organic process that “cannot be ‘set up’ as formal teams” (Pyrko, Dörfler, and Eden 2017, 392). Thus, purveyors of the concept may not technically count this group as a true CoP due to the deliberate methods by which participants were brought together. However, we suggest that, due to the scale of the challenges currently facing the local oyster industry and other natural resource issues, the need for rapid change to offset these challenges will sometimes require a more deliberate initiation. A formal setting such as this can allow participants to routinely share knowledge, which can allow them to thoroughly determine which challenges may be necessary to address first, and which solutions may require more time and resources to enact and therefore may be less feasible. As long as participants continue to share knowledge and develop a repertoire of resources (Wenger 2011) during regular, quarterly meetings, then this group is a true CoP capable of enacting positive change in the local oyster industry.

1.4.2 Development of the CoP

To continue improving communication, knowledge sharing, and trust building in the Alabama-Mississippi Oyster CoP, we have identified multiple opportunities and activities for future meetings and efforts.

The CoP has further opportunities to improve communication between oyster farmers, regulatory agencies, and other coastal groups. For example, it was suggested that future meetings may include coastal property owners and boaters to facilitate discussion about respective use of the coast. A meeting such as this can help bring mutual understanding and, when necessary, education to each group about their perceptions towards each other.

Secondly, the CoP could continue to host meetings between state agencies and farmers, especially if regulations change further or if communication issues continue to arise. The CoP can serve as an unbiased, third-party platform that can provide opportunities to enhance communication, especially between groups where interactions may be negative or tense. Neutral entities like the CoP can act as a facilitator and keep the focus on communicating relevant information, supporting the oyster industry, and providing a venue to resolve conflict.

There are also possibilities for the CoP to share knowledge about oyster aquaculture to non-community members. The CoP organizers have discussed hosting informatory meetings to people interested in becoming oyster farmers, work with schools to educate K-12 students about oysters and the industry and even invite state legislators to meetings to inform them about industry challenges. Direct communication and collaboration with legislators about the importance of oysters both naturally and economically could increase legislators' interest and investment into the industry, which could be an opportunity fulfilled by the CoP.

The CoP can also help provide its members more opportunities for knowledge and skill building. For example, farmers are able to apply for aquaculture grants to enhance their aquaculture operations through environmental groups, such as The Nature Conservancy's Supporting Oyster Aquaculture and Restoration Shellfish Growers Resiliency Fund (The Nature Conservancy 2024). However, some farmers may not have grant writing experience. Thus, the CoP may invite experts to lead a workshop to help guide farmers through the grant writing process, and therefore potentially help increase their chances of success in obtaining grants. The CoP can use these resources to find experts in different skill-building areas to help oyster farmers create more sustainable and resilient operations.

Finally, an important future role for the CoP is to continue building trust between groups and provide a constructive and neutral space for different stakeholder groups to interact. CoP facilitators from the Mississippi-Alabama Sea Grant Consortium will continue to include representatives from Mississippi and Alabama state agencies in meetings in order to keep lines of communication open between groups. In order to quantify whether trust between these groups is being strengthened, CoP facilitators may also incorporate other social science methods, such as interviews and surveys, to meet with participants one on one to discuss individual perceptions and experiences. Results from these practices could then be used to guide future meetings.

1.5 Summary

The development of a CoP for the oyster stakeholders of Alabama and Mississippi represents formal efforts to create regular and meaningful engagement between natural resource users, regulators, and other stakeholders. This case study highlights the importance of exchanging perceptions within a community in natural resources management. The first meeting of the Alabama-Mississippi Oyster CoP provided beneficial insights into the current struggles of the local oyster industry which guided later meetings that focused on increasing communication, sharing knowledge, and building trust between stakeholder groups, especially between oyster farmers and resource regulators. The CoP expanded communication between oyster stakeholders by providing spaces for various groups to meet together to address confusing and/or contentious topics, such as regulations or varying resource use goals. Secondly, CoP events can identify where resource-related knowledge is lacking and bring in experts to host educational or skill building events. Community groups such as this also work as a collection point for local ecological knowledge. Lastly, the CoP can help improve trust between resource users and managers by providing a constructive space for these two groups to meet and address concerns.

These three concepts are inherently important to addressing conflict in natural resources. An additional finding is that CoPs may also act as reservoirs for local ecological knowledge as participants meet and communicate their experiences. These four attributes enhance the CoP concept and can help widen its application in other natural resources settings.

Chapter 2: How are Oysters Managed in the Gulf? A Review of Management Strategies and Policies and their Implications for a Resilient Oyster Industry

Abstract

The eastern oyster (*Crassostrea virginica*) is an important species to the U.S. Gulf of Mexico as an economic, cultural, and ecological resource. Despite its importance, this species has been declining in the Gulf and is susceptible to numerous types of stressors, both natural and manmade. Effective policy and management techniques can help increase the resiliency of this species and its corresponding industry. A review of policy and management techniques across Gulf states using the coastal governance theoretical framework can help identify governance areas with high or low resilience and what potential recommendations can be made based on unique state policies. The coastal governance framework measures resiliency based on how coastal institutions respond to and recover from hazards, both manmade and natural, using its five core concepts: complexity, vulnerability, adaptive management, integration, and participation. This article includes a policy review and analysis from each of the five Gulf states relating to oyster aquaculture and wild oyster harvest. Results indicate that each of the five Gulf states incorporate each of these concepts to varying degrees, such as Louisiana's Oyster Task Force bolstering participation and the streamlined oyster aquaculture parks in Mississippi, Alabama, and Florida facilitating entry into the industry. However, a major challenge remains as governance occurs at the state scale, yet Gulf oysters are impacted by region-wide hazards.

2.1 Introduction

The eastern oyster (*Crassostrea virginica*) is a culturally, economically, and ecologically important species to the U.S. Gulf of Mexico (hereafter, "the Gulf"). Unfortunately, oyster numbers have decreased in the Gulf over recent decades due to anthropogenic and natural challenges, such as overharvesting and climate change. Oyster growth and survival is influenced by environmental factors and can be negatively impacted in multiple ways, such as increased hurricane frequency and strength that result in oyster reef damages (Solomon et al. 2014); higher carbon dioxide levels causing ocean acidification, which may limit biomineralization of oyster shell and reduce larval survival (Ivanina et al. 2013); and increased flooding event frequency causing mass mortalities (La Peyre et al. 2013, Pruett et al. 2021). Current oyster policy and management varies across the Gulf and reflects historic management goals and conditions (La Peyre et al. 2012). It is uncertain how suitable these policies and management approaches will be with continued changes to climate.

To determine suitability, policies and management approaches can be analyzed using the coastal governance framework. The coastal governance framework measures resiliency based on how coastal institutions respond to and recover from hazards, both manmade and natural (Dunning 2020). This framework examines five concepts in coastal institutions to measure resiliency: complexity, vulnerability, adaptive management, participation, and integration (see Table 2.2 for definitions). Policies and management strategies without these concepts are considered to have resilience gaps and will be analyzed below.

There are two main types of oyster production in the Gulf. The first is wild harvest, which entails harvesting oysters off of natural or planted reefs by hand or using dredges, tongs, or rakes. The second is aquaculture, also called oyster farming, which entails raising larval or juvenile oysters to harvestable size. Oysters harvested from natural or planted reefs typically go towards the shucked and/or frozen oyster market, while off-bottom farmed oysters are typically sold on the half-shell (Walton and Swann 2021). Regulations governing wild harvest and aquaculture have key similarities and differences across the states of the Gulf.

Oyster aquaculture in the northern Gulf can be further broken down into two types: off-bottom and on-bottom. Off-bottom aquaculture involves growing oysters in cages or bags in the water column and is a relatively new method of oyster cultivation in the Gulf. On-bottom can utilize one of three methods: cultivating oysters directly on the water bottom by spreading oyster shell or cultch and relying on natural settlement and attachment, by releasing larvae that are ready to set, by planting oyster spat (juvenile oysters), or by raising oysters in cages on the water bottom. Cultivating oysters directly on the water bottom without the use of cages is the more traditional method of raising oysters and has been in use for centuries (Kurlansky 2006). Both forms of aquaculture require leasing and/or specific permits if available in each state. Although on-bottom methods are a form of aquaculture, oysters raised via these methods are subject to natural growing conditions and are often harvested via traditional wild methods. Thus, for the remainder of this paper, forms of on-bottom aquaculture will be included in wild harvester methods unless otherwise stated.

Currently, there is a wide range in individual Gulf state oyster production (Figure 2.1). Shifts in oyster production across states and over time are due to variations in aquaculture productivity, state coastline length, estuary productivity, and manmade and natural hazards, among others (Gledhill et al. 2021, Pine et al. 2023, ADCNR 2024a). Examining how oyster management varies among states may allow resource managers to compare and contrast successful policy and management strategies that could influence oyster productivity. Further, this analysis is designed to help define whether the variations in production trends are due to environmental conditions and acute events rather than management decisions. Analyzing these policies will inform us about the resiliency of each state's oyster industry. Resiliency is defined as "the capacity of linked social-ecological systems to absorb recurrent disturbances such as hurricanes or floods so as to retain essential structures, processes, and feedbacks" (Adger et al. 2005). This research endeavored to investigate management strategies from the five U.S. Gulf of Mexico states to see where similarities and differences exist and relate these differences to state oyster landings/trends. Results are reported here to provide a comprehensive guide of oyster-related policies and regulations, identifying potential opportunities for increased industry sustainability and resiliency, especially to climate change.

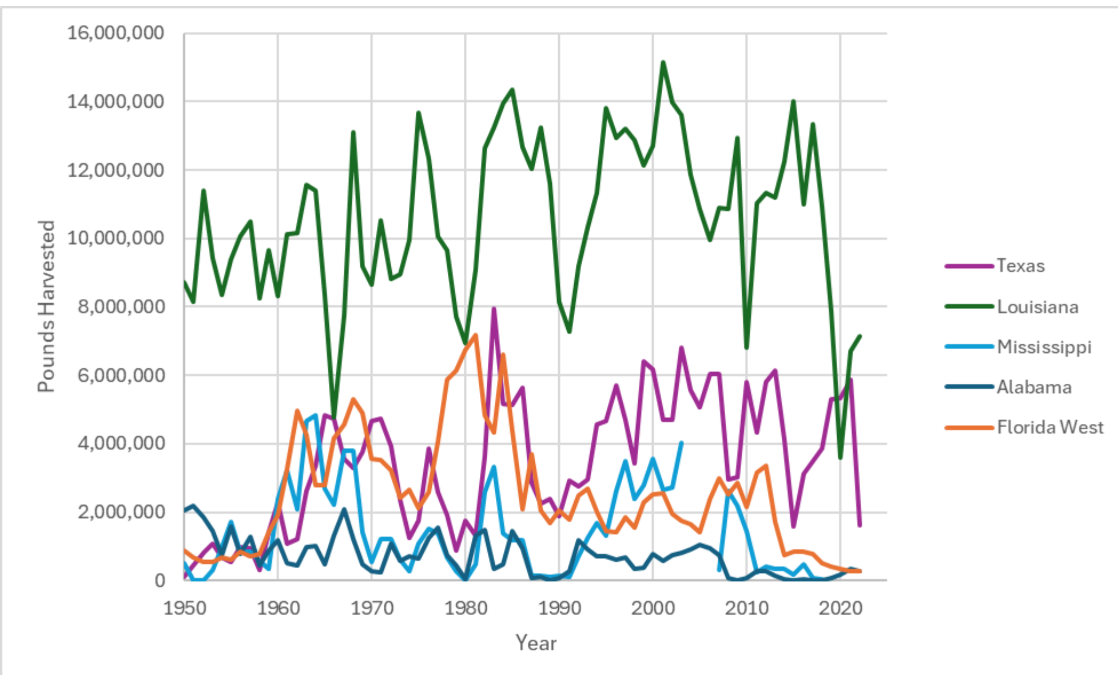


Figure 2.1. Pounds of oyster meat harvested in each Gulf state from 1950-2022 (NOAA 2023).

2.2 Case Context: What We Know About Oyster Policy

Oysters throughout the U.S. are predominantly managed by state fish and wildlife agencies and health agencies, not federal entities. Oysters are an estuarine species, and live in the inter and subtidal zones, which do not typically occur beyond the state water boundaries (typically three miles). Thus, federally-established entities such as the Gulf Coast Fishery

Management Council tend to have limited involvement in creating regulations for oyster management or restoration.

State agencies are primarily granted the power to manage and protect oysters through the U.S. Constitution. The 10th Amendment of the U.S. Constitution grants states what are known as "police powers", which are "the powers not delegated to the United States by the Constitution, nor prohibited by it to the States, are reserved to the States respectively, or to the people." Management of natural resources, which includes oysters, is not included in the Constitution; therefore, it is relegated to the states through this amendment. State agencies are also granted the power to manage and protect natural resources through U.S. Supreme Court cases, primarily *Martin v. Waddell*, 41 U.S. 367 (1842). This case provides the original Public Trust Doctrine ruling, stating that the public maintained a common right to fish in navigable and tidal water because those waters and their underlying lands were kept in trust by the state for the common use of the people. This decision was reaffirmed by *Illinois Central R. Co. v. Illinois*, 146 U.S. 387 in 1892. Each of the five Gulf states have included the Public Trust Doctrine in some form into their state constitutions. These include Section 59a of the Texas constitution, Article IX Part 1 of the Louisiana constitution, Section 12A of the Mississippi constitution, Amendment 543 of the Alabama constitution, and Section 7a of the Florida constitution.

Though management for wild oyster harvest is left to the states, some federal agencies provide resources for research and restoration efforts, such as the National Oceanic and Atmospheric Administration and the U.S. Fish and Wildlife Service. Some federal acts, such as the Clean Water Act, indirectly benefit oysters by regulations for clean water that protect aquatic animals. There is one federal body, however, that has more of a direct hand in regulating part of the oyster industry: the Food and Drug Administration (FDA). The FDA works closely with states to set and enforce standards to ensure the safety of oysters.. The FDA works closely with the Interstate Shellfish Sanitation Conference, which is a cooperative body between state and federal agencies, the shellfish industry, and academic researchers to create and distribute shellfish sanitation guidelines, known as the National Shellfish Sanitation Program (National Shellfish Sanitation Program 2023). These guidelines provide regulations on allowable thresholds of risk indicators, such as coliform bacteria and algal toxins, for oyster harvest and water classification. If waters where shellfish are grown exceed a certain concentration that could impact people, such as fecal coliforms, they are closed under these guidelines until detection rates fall below a certain threshold. Each of the five Gulf states follows these guidelines to prevent illness among oyster consumers.

Federal agencies have more involvement with oyster aquaculture. When applying for aquaculture permits, individuals must obtain permits from the U.S. Army Corps of Engineers, the U.S. Coast Guard, and the U.S. Fish and Wildlife Service, among others. Permits from these entities ensure that aquaculture practices do not interfere with navigable waters or threatened/endangered species.

Other federal involvement regarding the oyster industry is non-regulatory and includes cooperative programs such as the National Sea Grant College Program, which work closely with Gulf state universities and agencies to research and conduct programs on oyster restoration and aquaculture. There are four Sea Grant programs in the Gulf: Texas, Louisiana, Mississippi-Alabama, and Florida. Each of the Gulf Sea Grant programs provides research and resources for oyster programs in some way. These programs, as well as state agencies, are often supported by environmental non-governmental organizations, such as The Nature Conservancy, to conduct research on restoration projects. There are numerous private and non-governmental organizations throughout the Gulf that work with oyster restoration and/or coastal resilience in some way.

Clearly, as outlined above, oyster management, research, and restoration involve coordination and collaboration from many entities in the Gulf of Mexico. Despite the efforts of these entities, oyster conditions have declined in the Gulf (Hesterberg et al. 2020). This paper explores potential factors behind continued declines by examining the potential effects of oyster management and policy on oyster resource resilience using the coastal governance framework to determine where resilience gaps exist and where policies can increase resilience to current and future challenges. Secondly, this paper will compare and contrast policies and regulations across the Gulf states to determine how differing policies may influence production success.

2.3 Methods & Materials

Oyster management policy documents from each of the five Gulf states (Figure 2.2) were collected using Google and Nexis Uni in February 2023-March 2025. Further, news articles published after January 1, 2020 were considered for analysis to provide information on current issues in the Gulf oyster industry. We used the snowballing method (Hiebl 2021) while analyzing articles to find other topics relating to oysters in the Gulf that could provide further information on current issues and regulations. Documents were reviewed and individual attributes were recorded and tabulated (Table 2.1).

Table 2.1. Specific attributes recorded for each document used in this analysis. For Related Topics, each document was reviewed to determine whether they included that topic (yes vs no) and if so, which types were recorded.

Document Type	Actors	Policies Discussed (examples)	Related Topics
Legislative code	State or federal	Harvest	Industry stressor/hazard (Y/N)

Document Type	Actors	Policies Discussed (examples)	Related Topics
	agencies	regulations	
State/federal report	Non-governmental organizations (NGOs)	Sanitation regulations	Ecosystem services (Y/N)
Restoration and recovery plan	Private sector	Aquaculture permitting	Production type (aquaculture vs wild harvest)
Funding programs	University partners	Oyster monitoring techniques	Recent policy changes, recommendations, or research goals (Y/N)
State/federal web pages		Unique programs	
News source			

In order to evaluate the effects of these policies, we analyzed them using the coastal governance framework as described above and in Table 2.2. We reviewed each collected policy and management document to identify whether they contain coastal governance components. Policies related to each concept were graded on a 1-5 resilience scale, where 1 represents low resilience and 5 represents high resilience based on how well the policy incorporates a specific governance concept. After review, scores were averaged across concepts per state, and the state with the highest average score was deemed the most resilient.

Table 2.2. Modified from Dunning (2020). High scores (4-5) indicate a policy or regulation that could be conducive to resilient management, while low scores (1-3) indicate where the concept is lacking in policies and could represent challenges.

Coastal Governance Concept	Resilient Attribute in Institutions
Complexity	Institutions occur across scales and have clear boundaries and responsibilities (4-5)

	Institutions do not occur across more than one scale and/or have overlapping responsibilities (1-3)
Vulnerability	Institutions are aware of risks and can absorb change (4-5) Institutions do not consider hazards or stressors in policy (1-3)
Adaptive Management	Institutions incorporate learning into their decision-making process (4-5) Institutions do not incorporate learning into their decision-making processes (1-3)
Participation	Non-institutional stakeholders actively participate, or have participated, in management decision making (4-5) Stakeholders do not have, or have limited, opportunities to participate in management (1-3)
Integration	Institutions incorporate scientists and interdisciplinary information in decision making (4-5) Institutions do not incorporate interdisciplinary information in decision making (1-3)

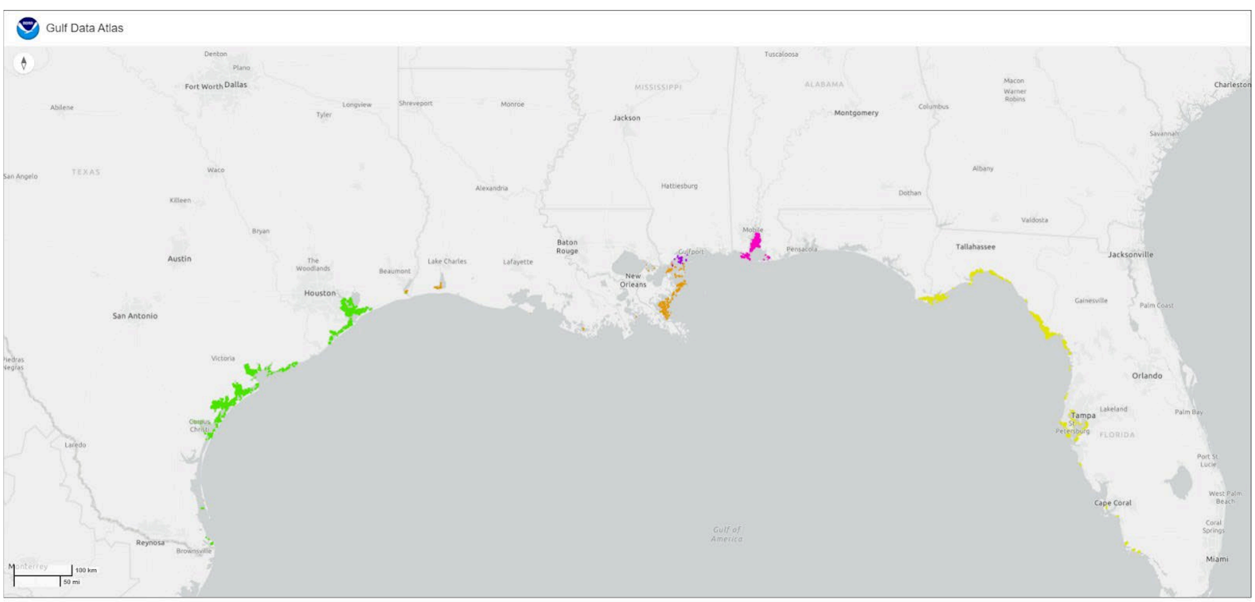


Figure 2.2: The five Gulf states and their historical wild oyster harvesting sites as of 2011 (National Centers for Environmental Information 2011).

2.4 Policy & Management Comparisons

One hundred and eight documents from state, federal, and private entities were collected and analyzed (Table 2.3).

Table 2.3: The number of documents originated from the five Gulf states, from Gulf-wide entities, or from federal agencies.

Document Origin	**Number of Documents**
Texas	18
Louisiana	21
Mississippi	19
Alabama	14
Florida	22
Gulf-wide	3
Federal	11
Total:	108

2.4.1 Similarities Among the States

2.4.1.1 Wild Harvest

In each of the five Gulf states, wild oyster populations and harvest are managed and regulated by each state's respective natural or marine resources agency. Regulations for the wild harvest of oysters have key similarities across all states, suggesting that the wider region manages wild harvest in much the same way. For example, wild harvest seasons typically range from September/October to April. However, season length does vary annually due to harvest limitations, weather, disease outbreak, manmade disasters, and poor water quality, among other reasons. Each state also requires wild oysters to be a minimum of 3 inches in length to be harvested, and that undersized oysters must be culled and returned to the reef from where they were harvested. The only difference here is that Louisiana allows the harvest of small oysters from public seed grounds during specific seasons for the planting of private leases (LDWF 2025). Each state also requires wild harvesters to obtain commercial or recreational harvest licenses before they can take oysters.

The gear types that fishermen use to harvest oysters are rakes, tongs, and dredges. Each Gulf state allows each type but with varying size and/or location limitations, like Texas's maximum dredge width of 14 in (TPWD n.d.b). Louisiana allows the use of dredges with distinct size specifications. However, private lease owners are able to use any kind of oyster harvesting gear, "as long as it does not impair or destroy the water bottom" (LDWF 2024, pg 17). In Florida, dredges are allowed on private leases with a license and are generally prohibited on public oyster reefs (Fla. Statues § 28-379.2525 2008).

It is important to note that across Gulf states, not all oyster reefs are open to harvest. Some reefs may be closed due to contamination or pollution levels, others may be closed due to restoration efforts, and others may be closed because they are designated as spawning reefs that supply larval oysters to surrounding harvestable reefs. Each of these types of reefs require their own regulations and/or management strategies to prevent harvest (Bersoza Hernandez et al. 2018, LDWF 2025).

2.4.1.2 Off-bottom aquaculture

One of the most important processes in establishing an off-bottom oyster aquaculture operation is obtaining all of the necessary permits and licenses from state and federal agencies, a system that is similar across all Gulf states. This process includes site selection, or where the operation will be located. Residents of each of the Gulf states are able to use their riparian rights to establish oyster aquaculture operations along their waterfront properties, provided they obtain site approval and the necessary permits and licenses (Ala. Admin. Code R. 220-4-.17, Fla. Admin. Code R. § 18-21.02, La. R.S. § 9:1102.2, MS Code § 49-15-9, TPWD n.d.*a*). Though the use of riparian rights and approval requirements vary slightly from state to state, two are consistent: aquaculture operations must not impede navigation and must be located in approved waters based on guidelines from the National Shellfish Sanitation Program. Other common location restrictions include nearness to "sensitive habitats" such as seagrass beds or natural oyster reefs and nearness to seabird rookeries (TPWD n.d.*a*), or nearness to endangered species habitat (Fla. Admin. Code R. § 18-21.021 2021).

Prospective farmers must submit plans on gear and operation type during the application process in all Gulf states. These plans entail the setup of their aquaculture operation, the number and types of gear to be used, the amount of oysters farmers intend to produce, transportation plans, and how farmers plan to implement quality control over their oysters, among others (Ala. Admin. Code R. § 220-4-.17 2014, MDMR 2024). These plans help ensure that aquaculture operations will comply with state and federal regulations for food safety and navigation.

To begin their oyster farm, oyster farmers must purchase oyster "seed", or small juvenile oysters, which are produced in hatcheries and reared in nurseries in each Gulf state. Because some farmed oysters can reproduce and potentially mix with natural oyster populations, some states have strict requirements for oyster seed genetics and disease testing. For example, oysters farmed in Texas must have been produced from oysters with genetics from Texas' natural stock and be disease-free; the same is true for Mississippi and Florida but regulations differ for the Gulf and Atlantic coasts (Banks et al. 2014, Texas Sea Grant n.d.). Louisiana and Alabama can import oysters from different genetic stocks from Gulf states provided that they are cleared for disease in a pathology laboratory beforehand (Banks et al. 2014).

In each of the five Gulf states, oyster farmers are able to harvest their oysters year-round. This is because farmers purchase oyster seed to raise rather than relying on natural spawning seasons like natural populations do (TPWD n.d.*a*). This is also because many farmers primarily grow triploid oysters rather than diploid. Triploid oysters are rarely reproductively viable due to their third set of chromosomes; thus they put their energy into biomass growth and can reach harvestable sizes faster than diploid oysters (Yang et al. 2018).

2.4.1.3 Marketing

Each of the five Gulf states runs their own form of marketing program to help bring consumer awareness to locally sourced products, including agriculture and seafood. These programs are named Texas Gulf Seafood (https://txgulfseafood.com/), Louisiana Wild Seafood Certification Program (https://www.louisianaseafood.com/), Mississippi Gulf Fresh Seafood (https://msseafood.com/), Alabama Seafood Marketing Commission (https://eatalabamaseafood.com/), and Fresh From Florida (https://www.followfreshfromflorida.com/). These programs are run by each state's agriculture or marine/natural resources departments and can promote oysters by directing consumers to seafood retailers, restaurants, and even oyster farms that serve oysters produced within the state. Some programs, such as Louisiana's, are more in-depth than others. Louisiana's program excludes farm-raised oysters, and Louisiana dealers must undergo training and receive certification before they can participate in the program, but once they do, they are able to mark their products with special branding identifying the product as Louisiana caught and processed. Other businesses participating in the program, such as restaurants and other seafood retailers, must only sell Louisiana caught and processed seafood.

2.4.2 Differences Between States

2.4.2.1 Supporting task forces

In some Gulf states, collaborative entities exist between state and industry groups. Louisiana has an established Oyster Task Force consisting of 21 voting and nonvoting members from multiple state agencies, oyster fishermen's associations, and seafood dealers. The goal of this task force is to "study and monitor the molluscan industry and to make recommendations for the maximization of benefit from that industry for the state of Louisiana and its citizens," (La. R.S. § 56:421). These efforts include monitoring water quality, increasing oyster production, generating marketing strategies, and acting as representatives for the industry before state and federal law-making bodies, among others (La. R.S. § 56:421). An oyster task force also technically exists in Mississippi; however, it lost its decision-making power in 2020 (MS House Bill 827 2020) and has not met since this time (MDMR 2025). Texas also has its own task force for oyster aquaculture known as the Commercial Oyster Mariculture Advisory Board, created by House Bill 3600 in 2021 (https://capitol.texas.gov/tlodocs/87R/billtext/html/HB03600I.htm). Florida has at least one task force for one of its river systems (GTM NERR 2021), but this task force is voluntary, not generated by state law.

2.4.2.2 Wild Harvest

States differ in several key strategies related to wild harvest management including differences in frequency, technique, and measured parameters (Table 2.4). The states monitor oyster reef health, population dynamics, water quality, and predators, among others. Texas monitors its natural oyster reefs on a monthly basis, Louisiana monitors different variables monthly and annually, and the other three states hold an annual schedule. Louisiana, Mississippi, and Alabama each use a combination of transect dives and dredges, while Texas and Florida only use one of the two techniques. These techniques can be used to provide both qualitative and quantitative data to help determine a reef's overall health (J. Rider, email to author, Jan. 22, 2024). Each state varies slightly in what biotic and abiotic factors it measures. For example, Texas documents the kinds of vegetation brought up in their dredges. Other states monitor for the presence of a parasitic oyster disease known as dermo regularly, while others do so irregularly or not at all (J. Herrmann, email to author, Jan. 20, 2024). Some states measure turbidity and/or pH levels during their monitoring efforts, while others, like Louisiana and Alabama, do not.

Table 2.4. The survey techniques, frequency, and measured parameters utilized by each of the five Gulf states.

State	Survey Type	Frequency	Biotic Parameters	Abiotic Parameters	Surveying Agency
Texas (TPWD Records Department, email to author, Jan. 2024)	Dredge	Monthly	# and measurements of live, dead, and spat oysters Non-oyster organisms Vegetation	Temperature Salinity DO Turbidity	TX Parks & Wildlife
Louisiana (LDWF 2025)	Hand dredge 1 m^2 frame dives	Monthly (annual stock assessment in July)	# live and dead oysters # predators Other reef-associated organisms	Temperature DO Salinity	LA Department of Wildlife and Fisheries
Mississippi (J. Rider, email to author, Jan. 2024)	Dredge 1 m^2 dives	Annual, April-October	# live oysters, fresh boxes, spat Predator presence Disease prevalence	Surface/bottom water temperature Surface/bottom water salinity Surface/bottom water pH Surface/bottom water DO Turbidity	MDMR Shellfish Bureau
Alabama (J. Herrmann, email to author, Jan. 2024)	Transect dives Hand dredge Patent	Annual, Summer	# live oysters oyster density Oyster drill frequency Dermo^	Salinity Temperature DO pH^	ADCNR Marine Resource Division

	tongs				
Florida (Radabaugh et al. 2019)	0.25-1 m^2 quadrats*	Annual, Biannual** Monthly**	Oyster density & size-frequency distribution Spat settlement Disease prevalence Associated species	Temperature Salinity DO pH Turbidity Reef areal dimensions and height Tidal emersion	Florida Wildlife Commission, FL Department of Agriculture and Consumer Services

^Dermo and pH are only tested with concurrent, separate research projects primarily conducted via other entities (J. Herrmann, email to author, 1/26/2024).
*The size of the quadrat depends on oyster density; 0.25 m^2 are used for high oyster density areas; 1.00 m^2 are used for low density areas.
**Reefs in Apalachicola and the Everglades are subject to biannual monitoring as dictated in a fishery recovery plan and the Comprehensive Everglades Restoration Plan. Monthly sampling for larval recruitment occurs in Apalachicola and the Everglades

2.4.2.3 Off-bottom aquaculture

For off-bottom aquaculture, the predominant differences lie in how each state dictates the permitting process. In three of the five Gulf states, Texas, Louisiana, and Alabama, prospective oyster farmers must go through a multi-stage permitting process before they can begin their operations with a primary focus on farm site selection. In these states would-be farmers need to obtain approval from at least five different state and federal agencies. These include the U.S. Army Corps of Engineers and/or the U.S. Coast Guard, each state's health department, each state's natural or marine resources department, and each state's environmental management agency (Ala. Admin. Code R. § 220-4-.17 2014, LDWF n.d.*a*, TPWD n.d.*a*). Additional entities include the Texas General Lands Office and Department of Agriculture and the Louisiana Department of Energy and Natural Resources (LDWF n.d.*a*, TPWD n.d.*a*). In Mississippi and Florida, however, prospective farmers can apply for a parcel of water that has already been identified, pre-approved and pre-permitted by each state, thereby bypassing the need for farmers to obtain permits. Alabama also has two parks that are managed by independent organizations. In

Mississippi, these parcels are located in the Deer Island Aquaculture Park and are regulated by the Mississippi Department of Marine Resources (MDMR 2024). In Florida, prospective farmers can choose from pre-approved parcels in 10 different coastal counties, or suggest new ones (Fla. Admin. Code R. § 18-21.021 2021).

The states also differ in their private leasing programs for oyster aquaculture. As discussed above, there are two types of on-bottom aquaculture. On-bottom aquaculture without the use of cages has been practiced since the late 1800s and is often implemented by state natural resources agencies to replenish or restore historical oyster reefs. Citizens are also allowed to lease bottom water areas (also known as submerged lands) from their respective states to cultivate and harvest oysters. Louisiana has been leasing bottom waters since 1902 (Louisiana Legislative Auditor 2015), with a large proportion of the state's oyster population under private leases, approximately 400,000 acres (LDWF n.d.*b*). Texas private leases were recently expanded in September 2023, after the passage of Senate Bill 1032 (Bonnot 2023).

On-bottom aquaculture with the use of gear is not practiced among all Gulf states, though is becoming more prevalent. Mississippi recently initiated a private leasing program in mid-2023 to expand on-bottom aquaculture (MDMR 2023). Florida also offers on-bottom leases for aquaculture production; however, these are primarily utilized for clam production rather than oyster (FDACS 2022). Similarly in Alabama, most if not all oyster aquaculture is off-bottom, though on-bottom leases exist (R. Grice, email to author, July 12, 2024). In Louisiana, farmers can use on- or off-bottom gear provided they obtain an Alternative Oyster Culture Permit (LDWF n.d.*a*).

In some Gulf states, oyster farmers must complete some form of training either before or throughout the life of their farming operation. In Florida, farmers must annually complete the

Shellfish Harvester Education Training so they can ensure they keep up with processing guidelines from the National Shellfish Sanitation Program (Fla. Admin. Code § 5L-1.003). In Mississippi, prospective farmers must participate in the Off-Bottom Oyster Aquaculture Program in order to sublease from the Deer Island Aquaculture Park (MDMR 2024). In Louisiana, aquaculture practitioners must complete an online Oyster Harvester Training before they can receive their Oyster Harvester License and their Alternative Oyster Culture Permit (LDWF n.d.*a*, LDWF n.d.*c*). This training must be repeated every three years and is required for oyster harvesters as well. Alabama also requires training that their farmers and harvesters must take every 5 years (Ala. Admin. Code R. § 220-3-.02 2021). Texas does not formally require aquaculture training, but institutions within the state provides or has provided aquaculture education. Past aquaculture training courses in Alabama were sponsored by the Mississippi-Alabama Sea Grant Consortium through Auburn University (Walton and Swann 2021) and may continue through Commercial Oyster Aquaculture Sector Training programs (MASGC 2024). In Texas, the Texas A&M University Harte Research Institute Oyster Resource and Recovery Center recently launched online training courses for would-be farmers (McCauley 2024), highlighting how research and extension take large roles in supporting the oyster industry in these two states.

The state regulatory agencies involved in aquaculture permitting and monitoring are not parallel across Gulf states. In Mississippi, the Department of Marine Resources is solely responsible for monitoring water quality per the National Shellfish Sanitation Program guidelines (MS Code of Rules § 22-1-3), not the state's health department. Similarly, in Florida, oyster harvest and aquaculture is monitored for public health purposes by the Florida Department of Agriculture and Consumer Services, not the Florida Department of Health (Fla. Admin. Code

§ 5L-1.003 2023). In the other three Gulf states, their respective public health departments monitor water quality and oyster harvesting/aquaculture operations (TCEQ 2024, TPWD n.d.*a*). In Florida, aquaculture is completely managed and regulated by the Florida Department of Agriculture and Consumer Services Division of Aquaculture.

There are other differences in aquaculture regulations across Gulf states. In Texas, oyster aquaculture is referred to as "mariculture", and potential farmers must both obtain written permission from adjacent landowners and submit their plans for public comment before they can commence their operations (TPWD n.d.*a*). Texas is also the last Gulf state to implement oyster aquaculture, with operations beginning in 2019 (Watkins 2023). In Mississippi, farmers (and wild harvesters, when there is a season) can sell their oysters directly to consumers so long as they possess a Fresh Product Permit from the Mississippi Department of Marine Resources (MS Code of Rules § 22-9-5). In Florida, oysters have to be processed and tagged by a certified dealer first before the farmer can sell directly to the consumer (FDACS 2023). In the other three Gulf states, farmers and harvesters must sell their oysters to licensed seafood dealers, which then sell to restaurants or processors (Ala. Admin. Code § 420-3-18 2020, LDWF n.d.*d*, TPWD n.d.*a*). Farmers and harvesters can become seafood dealers themselves by obtaining the necessary licenses from their state's health departments to ensure that proper sanitation guidelines are followed (i.e., TPWD n.d.*a*).

2.5 Results & Discussion

2.5.1 Complexity

Complex systems are defined as systems that are uncertain and unpredictable in their behavior, where changes on a small scale can cause large scale impacts (Ratter 2013). Although oysters exist as connected populations across the entire Gulf coast, management occurs at the state level. Actions in one state can heavily impact oysters, both wild harvest and aquaculture, in another state, such as the openings of the Bonnet Carré Spillway in Louisiana in 2019 that devastated Mississippi oyster populations (Pruett et al. 2021), indicating that oyster populations are highly complex systems.

Challenges due to complexity can be mitigated by clear and cross-scale institutional boundaries and responsibilities (Dunning 2020). Two programs exist across an inter-state scale; the first is the Interstate Shellfish Sanitation Conference, addressed earlier, and the Gulf States Marine Fisheries Commission. This organization was signed into law in 1949 with a goal "to make inquiry and ascertain from time to time such methods, practices, circumstances and conditions as may be disclosed for bringing about the conservation and the prevention of the depletion and physical waste of the fisheries, marine, shell and anadromous, of the Gulf Coast" (P.L. 81-66). Each Gulf state appoints three people to the commission, including a conservation official, a member of the state's legislature, and a citizen with an interest in marine fisheries. However, this commission acts as an advisory council to the Gulf states and their marine resource agencies; it does not have any regulatory power (GSMFC 2023).

Despite the fact that oyster populations are connected via larval flow across the Gulf, governance and management scales exist at the state level and below. There is little input from federal organizations in shaping and implementing policy beyond the National Shellfish Sanitation Program, which oversees the U.S. shellfish policy, and USDA risk management programs such as oyster crop insurance (USDA 2024). Thus, governance is centralized at the state level. Local institutions, such as towns and counties, have some governance involvement; they must follow the state's policies but can have different independent programs that can influence overall oyster resiliency. One such program is the Alabama Coastal Foundation, which sponsors an oyster shell recycling program that supports continued enhancement and provision of habitat for oyster setting to promote local population resiliency (Alabama Coastal Foundation 2025).

Though complexity management within the oyster industry is limited to the state scale and below in terms of regulatory power, some jurisdictional overlap in responsibilities exists across some agencies, potentially causing confusion among stakeholders. As discussed in earlier sections, there are only one or two agencies per state involved in oyster management for both aquaculture and wild harvest, such as the Mississippi Department of Marine Resources. However, some jurisdictional confusion may exist when two separate agencies regulate the same resource or have different responsibilities across states. For example, in states such as Alabama, Louisiana, and Texas, the health departments determine harvestable areas and water closures based on National Shellfish Sanitation Program (NSSP) guidelines (Ala. Admin. Code § 420-3-18, La. R.S. § 40:5.3 2021, TX Admin. Code § 25-1-241). On the other hand, in Mississippi, the Department of Marine Resources follows the NSSP and maintains shellfish sanitation, not the state's health department (MS Code of Rules § 22-1-3). Similarly in Florida, the Florida Department of Agriculture and Consumer Services follows the NSSP for shellfish growing areas and sanitation, not the Department of Health (Fl. Admin. Code § 5L-1.003). Many stakeholders may not know about these differences and thus may have difficulties acquiring necessary information and permits if they work across states. This could also be detrimental during disaster response, as having more than one agency involved in management could slow down recovery options.

Further, some state agencies not directly involved in oyster management may directly affect oyster populations through their activities. One such example is the Coastal Protection and

Restoration Authority of Louisiana and the U.S. Army Corps of Engineers, which manage river and sediment diversion and/or restoration projects (Killebrew and Khalil 2018, U.S. Army Corps of Engineers n.d.). Agencies and projects such as these that manage water quality and coastal restoration can affect oysters within and around their state by the movement of sediment and/or water diversions, further adding to the complexity of this system.

2.5.2 Vulnerability

The Gulf of Mexico has a long history of major weather events, such as hurricanes, droughts, and flooding and a more recent history of manmade disasters, such as oil spills and resource overharvest (Vanderkooy 2012, Pruett et al. 2024). All five states are aware of the various risks and have both currently and historically made policy to recognize and respond to them. For example, of the 108 documents collected, 69 mentioned hazards or challenges faced by the oyster industry (Table 2.5). The documents discussed a total of 16 different hazards affecting the industry, with a heavier focus on public health, hurricanes and storms, oil spills, and flooding/freshwater influx.

One method each state uses to monitor their vulnerability is by monitoring their wild oyster stock. As seen in Table 2.4, each state uses a different combination of monitoring techniques and frequencies to continuously monitor oyster habitat and populations. Using these techniques, resource managers can identify reduced numbers and adjust harvest restrictions for wild oysters as necessary to mitigate the effects of harvest or potential natural disasters.

Table 2.5. The types and frequencies of different hazards, both manmade and natural, threatening the oyster industry mentioned in the analyzed documents.

Type of Hazard	Frequency Mentioned (n)
Public health outbreak/foodborne illness	20

Hurricanes/storms	19
Oil spills	16
Flooding/freshwater influx	14
Drought	8
Poor water quality	8
Invasive/predatory species	7
Overharvesting	5
Dredging	5
Harmful algal blooms	4
Salinity fluctuations	4
Oyster disease	4
Sedimentation	2
Loss of habitat	2
COVID 19	1
Hypoxia events	1

Off-bottom aquaculture methods were introduced to the Gulf in 2009 as a response to the perceived vulnerability within the wild oyster populations. Off-bottom aquaculture is a controlled technique for producing oysters in which the oyster farmer can move equipment within the water column and to alternate locations, change handling techniques, and alter harvesting strategies in response to fluctuating environmental conditions. Further, aquaculture is a more consistent method of oyster production; as stated earlier, oysters can be produced year-round through this method (Walton et al. 2013, Walton and Swann 2021). Despite its benefits, off-bottom aquaculture is not without its own vulnerabilities, such as those in Table 2.5 and others, including long permitting times, high operation costs, strict location regulations, and environmental fluctuations (Beckensteiner et al. 2020).

2.5.3 Adaptive Management & Integration

Another key component of the coastal governance concept is the capability of adaptive management, which indicates that states are able to prepare for and absorb change when need be. Institutions demonstrate adaptive management by engaging in policy learning, which is when policymakers acquire and implement new knowledge (Dunning 2020). Gulf states have demonstrated policy learning in their oyster regulations by adopting new approaches, policies, and restoration based on new understandings and research findings. Much of this policy learning occurs via integration of novel research and findings from local universities and non-governmental organizations; thus, the results of both concepts are combined here.

One example of this integrated research is identifying new areas for oyster viability. For much of oyster restoration history, managers and harvesters have focused on planting cultch in areas with known oyster reefs to provide settling locations for oyster spat. However, many estuarine regions in the Gulf have experienced changed water regimes due to land use change and coastal construction, causing altered habitat viability options for oysters. New research involves studying the hydrology and larval transport between reefs to identify locations where oyster larvae could settle, thus indicating new sites for cultch planting and reef formation, and examining changes in these areas based on projected future conditions. This research has occurred across Gulf states with both state agencies and university researchers (Mississippi: Linhoss et al. 2016; Alabama: Wang et al. 2020; Florida: Geselbracht et al. 2024; Texas and Louisiana: La Peyre et al. 2024). Oyster research is broadly conducted across Gulf institutions, and other common research topics along the Gulf include, but are not limited to, planning spawning sanctuaries for oysters (MDMR 2022, ADCNR 2024b) and improving water quality monitoring near oyster reefs (TCEQ 2024).

One key example of policy learning is the implementation of off-bottom oyster aquaculture across Gulf states. These techniques are novel for the Gulf of Mexico and have only been implemented since 2009 (Walton and Swann 2021). Off-bottom aquaculture is viewed as a diversified and sustainable method to produce oysters that provides many of the same ecosystem services as natural oyster reefs do. Another benefit is that oyster larvae, or seed, are produced in hatcheries across the Gulf for aquaculture rearing; thus, aquaculture does not rely on wild spawning for reproduction (Botta et al. 2020), indicating potentially faster recovery times after hazards. Oyster farmers also have more control over the growing process, such as location and density (Walton and Swann 2021).

Another example of policy learning is the expansion of private leasing programs. The Gulf states of Mississippi and Texas created or expanded their on-bottom private leasing programs in 2023. When private citizens lease submerged lands from their states, they accept responsibility for management and cultivation of the oysters on those parcels. Citizens are also able to make decisions relating to management or restoration faster than state agencies, so they can begin recovery faster after hazards (Lee 2023). As a result, the expansion of these programs could increase the resilience of wild oyster reefs. According to Lee (2023), on-bottom leases can allow lease owners to have faster response times to oyster mortality events after hurricanes or floods. Effectively, they do not have to wait for funding or governmental approval to begin restoration as a state agency would. These faster response times help populations recover after hazards and is believed to be a key reason why Louisiana’s oysters have demonstrated higher recovery success after hazards. However, Mississippi’s decision to initiate oyster leases is facing backlash from oyster harvesters who believe that this action will take away their access to historic oyster reefs (Glowacki and Baronich 2025).

A final example of policy learning is the implementation of oyster shell recycling programs. These programs are typically run by not-for-profit organizations, such as the Alabama Coastal Foundation, the Galveston Bay Foundation, The Nature Conservancy, and the Coalition to Restore Coastal Louisiana. These programs work with oyster-selling restaurants to collect oyster shell that can be used in reef restoration. These programs were brought about to help return oyster shell to the water, rather than to landfills, to help provide hard substrate for generating or keeping up with oyster reefs. While these programs are not typically state-run, one state added benefits to businesses that participate in the programs. In 2023, Louisiana created a tax credit program for restaurants participating in oyster shell recycling. Through this program, restaurants can receive a $1.00 credit per 50 pounds of oyster shell recycled, up to $2,000 (La. R.S. § 47:6043).

2.5.4 Participation

Participation, or the incorporation of non-institutional stakeholders in management decisions, exists at varying levels across each of the five Gulf states. For most of the Gulf states, regulatory agencies provide platforms for stakeholder input in the form of public meetings and public comment on regulatory documents (ADCNR 2024a, MDMR 2021, TPWD 2024, Turner 2025). In Louisiana and Texas, stakeholders are more directly involved in management via the Oyster Task Force and the Commercial Oyster Mariculture Advisory Board, respectively. As stated previously, the Louisiana task force incorporates industry stakeholders, researchers, and resource managers in order to develop and implement oyster management. Florida has a voluntary version of these task forces, which effectively act as advisory bodies to regulatory agencies. In the past, Mississippi's Commission on Marine Resources, which housed an oyster task force, worked to incorporate industry and research stakeholders in oyster management. However, this body lost its decision-making connections in 2020 when it became an advisory-only role (MS House Bill 827 2020). Through this action, stakeholder participation in management was reduced in Mississippi (Glowacki 2025).

Stakeholders may become involved in non-governmental groups or associations, such as the Florida Aquaculture Association (https://www.flaa.org/), the Gulf Shellfish Institute (https://www.gulfshellfish.org/), and the Gulf Shellfish Farmers Association (https://www.gulfshellfishfarmers.org/), among others. Though these groups are not policy-making, they do bring stakeholders together to increase lobbying potential, thus allowing them to influence oyster-related governance.

2.5.5 Resiliency

While the Gulf states exhibit each of the five concepts of coastal governance in some capacity, it is difficult to denote them as resilient or not resilient (Table 2.6). Unfortunately, there are many negative factors affecting Gulf oyster populations. Many strategies have already been tried for oyster restoration with varying levels of success (La Peyre et al. 2014, Bersoza Hernandez et al. 2018, Pine et al. 2023). Restoration efforts such as cultch planting have been in practice since the early 1900s (Vanderkooy 2012), yet oyster populations are struggling to recover as exemplified by efforts in the Mississippi Sound and Apalachicola Bay, Florida, as both systems took years to reopen harvest after natural hazard events. Many documents discuss research and restoration projects that have started as a result of a major hazard, indicating that change occurs retroactively rather than proactively within the Gulf oyster industry. Despite each state's best efforts for planning and restoration, all it could take is one major disaster or a series of smaller disasters for a state to lose its ability to commercially produce oysters.

Table 2.6. Average analysis score for each Gulf state oyster policy and management. Scores reflect how each state incorporates each coastal governance concept (score based on attributes from Table 2.2).

State	**Complexity**		**Vulnerability**	**Adaptive Management**	**Integration**	**Participation**	**Average Score**
	Occur across scales	*Have clear boundaries*	*Aware of risks*	*Incorporate learning in decision making*	*Incorporate interdisciplinary information in decision making*	*Stakeholders are involved in decision making*	
TX	1 – occurs only at state scale	2 – multiple agencies involved in oyster production	5	5	5	4 – mariculture advisory board	3.67
LA	1– occurs only at state scale	2 - multiple agencies involved in oyster production	5	5	5	5 – Oyster Task Force	3.83
MS	1– occurs only at state scale	4 – one agency regulates oyster production	5	5	5	2 – limited to public meetings	3.67
AL	1– occurs only at state scale	2 - multiple agencies involved in oyster production	5	5	5	2 – limited to public meetings	3.33
FL	1– occurs only at state scale	2 - multiple agencies involved	5	5	5	2 – limited to public meetings	3.33

		in oyster production					

These results may indicate why Louisiana continues to produce the most oysters, at least via wild harvest. They incorporate high levels of participation and allow management to occur individually on private leases and have been doing so for a century. Early active management may have given Louisiana oysters a stronger foundation for resiliency by building in more participation in management systems and actively working with different stakeholder groups to integrate novel research findings that inform adaptive management strategies.

2.5.5.1 Emerging Opportunities

One method to decrease regulatory confusion and potentially increase resiliency in Gulf oyster aquaculture is by establishing aquaculture parks. Aquaculture parks are pre-permitted areas designated for oyster aquaculture, which drastically decreases the time a would-be farmer needs to start operations. Some states, such as Mississippi, Alabama, and Florida, already have established parks or aquaculture zones (Walton and Swann 2021, Fla. Admin. Code R. § 18-21.021 2021, MDMR 2024). Expanding these across Gulf states could help increase the number of oyster farms, which could help enhance production, restore valuable ecosystem services, and even potentially aid in restoration efforts, thus increasing resiliency.

Secondly, increasing participation in management decisions could help increase industry resiliency, especially for wild harvest. Oyster harvest is a generational activity in the Gulf of Mexico, indicating local ecological knowledge that may benefit management has been passed down through families. By providing more platforms for participation, such as task forces and advisory councils, this local ecological knowledge could be synthesized with monitoring data collected by the state to identify new areas and resources for restoration and/or research.

Finally, the Gulf of Mexico is not the only U.S. region that produces oysters. Oyster industries facing similar struggles are prominent on the East and West coasts, as well as worldwide (Botta et al. 2020). Gulf states could benefit by comparing policies with these other oyster-producing areas to identify how management efforts and regulations compare. Two regions in particular, the Chesapeake Bay and Hudson Bay, faced issues with major oyster population decline, yet are currently steadily improving their numbers (Smith et al. 2022, Grizzle et al. 2024). Future work could identify and compare restoration practices and regulation evolution between regions. These analyses could identify learning opportunities for Gulf institutions, especially if other regions are producing and/or restoring more oysters using different strategies.

2.6 Summary

This work represents a synthesis of oyster management and policy across the U.S. Gulf of Mexico states in order to identify hazard resilience using the framework. The Gulf oyster industry is composed of two sectors, wild harvest and oyster aquaculture. Overall, the states are similar in how they manage and regulate their oyster resources, yet the coastal governance framework identified key differences that may impact the level of resiliency for oyster production within each state. These differences include levels of stakeholder participation and variations in agency responsibility that do not transcend the state scale. All five Gulf states remain invested in oyster research and restoration, yet the resource remains vulnerable to hazardous events, thus opportunities to improve resiliency exist.

Chapter 3: Identifying Adaptive Governance and Resiliency Gaps in the Alabama and Mississippi Oyster Industries via Stakeholder Perceptions

Abstract

The adaptive governance theoretical framework measures resilience in complex socio-ecological systems by identifying whether the systems implement rules that can evolve as conditions change. This study used stakeholder perceptions collected via qualitative methodologies to search for these traits within the Alabama and Mississippi oyster industries to measure industry resilience, especially towards climate change. We developed a 19-question interview and a 10-question surveys that were distributed to a total of 86 stakeholders throughout the Alabama and Mississippi oyster communities during 2023-2024, focusing on the role of governance on oyster aquaculture and wild oyster harvest. Results indicated the presence and absence of each adaptive governance attribute, and how increased communication and collaboration between stakeholder groups can help address challenges throughout the industry. Specifically, increased communication and collaboration can help institutions and stakeholder groups 1) provide each other with accurate information about oysters and their related regulations; 2) resolve and prevent conflict between user groups; 3) induce effective rule compliance by creating production-specific policy across both states; 4) develop and implement beneficial infrastructure for both oyster aquaculture and wild harvest; and 5) collect, analyze, and share information about potential environmental impacts and developing mitigation strategies. Using the adaptive governance framework, a number of opportunities were identified that could address challenges facing the oyster industry in Alabama and Mississippi.

3.1 Introduction

The oyster industry throughout the northern Gulf of Mexico, centered on the eastern oyster (*Crassostrea virginica*), is one of the most economically and culturally important social-ecological systems in the United States (Grabowski and Peterson 2007, National Marine Fisheries Service 2024). This industry also provides valuable cultural connections to the Gulf for generational fishermen, with the oyster acting as a symbol for a particular way of life along the Gulf Coast (Coleman 2003). Oyster numbers have been fluctuating throughout the region and worldwide over the past century due to a variety of factors, including overharvesting and natural disasters (Beck et al. 2011, zu Ermgassen 2013). Climate change is expected to exacerbate oyster mortality in the Gulf through worsening hurricanes, droughts, and rising ocean temperatures in upcoming decades (Allen et al. 2023, Plumlee et al. 2024). Thus, identifying resiliency gaps in this industry, or gaps that would prevent oyster stakeholders from recovering from shocks, is inherent to its existence and success in the future.

There are two forms of oyster production in the Gulf - wild harvest and oyster aquaculture. Wild harvest involves directly taking oysters from natural or planted reefs and is typically managed by state agencies and can also be referred to as oyster fishing or oyster tonging. Oyster aquaculture involves growing oysters on the water bottom (referred to as "on-bottom") or in the water column via the use of floating cages or bags (referred to as "off-bottom") and is commonly referred to as oyster farming. Each Gulf state has both types of oyster production, yet for this study we will focus specifically on the states of Alabama and Mississippi. These two states were historically major oyster producers on the Gulf yet have faced oyster production declines in recent decades (ADCNR 2023, Pruett et al. 2024).

In order to better characterize such an important industry that has faced major threats to its very survival, qualitative research methods, such as interviews and surveys, and analysis via specific theoretical frameworks, can be useful tools for collecting and interpreting stakeholder perceptions. These data on stakeholder perceptions of industry challenges can allow researchers to identify gaps in resiliency related to the resource, especially considering climate change. Resiliency is the ability of a system to maintain its essential functions and continue performing after major disasters or disturbances (Adger et al. 2005). This concept is especially important for analyzing socio-ecological systems, which are systems with tightly linked interactions between people and a specific resource (Ostrom 2009). Examples include fisheries, timber, and hunting industries.

3.1.1 Theoretical Framework - Adaptive Governance

To understand how the Alabama and Mississippi oyster industries are responding to their various challenges and to identify resilience gaps, we analyzed our qualitative results using the adaptive governance framework. Adaptive governance was coined by Dietz et al. (2003) and can be simply defined as governance across scales in complex socio-ecological systems with rules that can evolve as conditions change. In this framework, governance occurs across four entities: actors, which are individual people or groups; social networks, or the interactions between actors; organizations, or formalized agencies with defined goals and actions; and institutions, or the informal and formal rules in use within a system (Österblom and Folke 2013, pg. 3). According to Dietz et al. (2003), systems with effective adaptive governance have five requirements displayed across entities and implement three strategies to meet these requirements (Table 3.1).

Adaptive governance has been applied to other fisheries socio-ecological systems worldwide (Nunan 2010, Österblom and Folke 2013, Datta and Chaffin 2022), yet has not been applied to the oyster industries of Mississippi and Alabama. Thus, utilizing this framework can help identify whether the Mississippi and Alabama oyster fisheries are flexible and responsive to environmental and/or manmade hazards and where challenges to these practices may exist. For example, Nunan (2010) found challenges relating to the large scale of fisheries management as well as complications across management scales.

Table 3.1. Descriptions of the adaptive governance requirements (1-5) and strategies (1-3) (from Dietz et al. 2003).

Requirement (R) or Strategy (S)	Descriptions
Providing information (R1)	Resource management organizations provide information about the resource, its management, and about human-environment interactions that affect the resource
Dealing with conflict (R2)	Resource management organizations incorporate participation in governance and implement conflict resolutions
Inducing rule compliance (R3)	Rules of resource use are followed with systems of effective consequences if rules are not followed
Providing infrastructure (R4)	Groups provide functional technology for resource use and monitoring
Being prepared for change (R5)	Institutions must be willing to incorporate new knowledge in policy-making
Analytic deliberation (S1)	Collaboration and communication between different stakeholder groups
Nesting (S2)	Organizations occur across political scales and are nested in layers
Institutional variety (S3)	Rules should come from a variety of sources, such as governing laws, community self-regulation, and market incentives

This adaptive governance framework was used to identify resilience gaps as perceived by stakeholders in the Alabama and Mississippi oyster industries. Identifying resilience gaps can provide opportunities for new policy making and entity collaboration to address challenges and implement preparedness for future changes, especially related to worsening climate change.

The goal of this study is to identify the resilience gaps in order to bolster the Mississippi and Alabama oyster industries especially relating to regulation and climate change challenges. We utilized interviews and surveys evaluated through the adaptive governance theoretical framework, to allow us to gather information about industry resilience gaps directly from the affected stakeholders.

3.2 Methods

3.2.1 Stakeholder Identification

Potential interview/survey participants were identified through multiple methods. The primary method was using a participant list from the Alabama-Mississippi Oyster Community of Practice, a community group made up of multiple oyster stakeholder groups, such as oyster farmers, researchers, non-governmental organizations, and seafood processors (see Sower et al. 2025 for more information). These initial participants were also asked about other relevant stakeholders in the industry who might be willing to complete interviews (per the snowballing method; Hiebl 2021). Other participants were identified via their participation in events held by the Mississippi-Alabama Sea Grant Consortium and/or the Alabama Cooperative Extension System. Finally, stakeholder types such as seafood processors and seafood restaurateurs were identified using state permit and Internet searches.

3.2.2 Interviews

Interviews were semi-structured and contained 19 questions (Appendix 1) relating to ecosystem services, industry challenges, regulations, and climate change. Each participant was contacted two times to attempt to schedule an interview. Interviews occurred in person, over the phone, or via Zoom, and began in June 2023 and ended in July 2024. Recording devices were not used during interviews as oyster issues can be contentious and we wanted our participants to feel comfortable and answer questions truthfully (Adams and Cox 2008). Thus, notes were taken by hand and transcribed. Interview responses have been kept confidential as per Auburn University's Institutional Review Board (#22-445 EX 2210) requirements.

3.2.3 Interview Coding

We developed a coding manual so that each code represented one of the five requirements and three strategies of the adaptive governance framework. Certain requirements and strategies were assigned to specific interview questions (Table 3.2) to reduce variation in coding cross validation. For coding cross validation, the primary author coded all interviews, and a coauthor reviewed 20% of interviews, with 75% agreement using the coding manual (O'Connor and Joffe 2020).

Table 3.2. Interview and survey coding manual based on adaptive governance requirements (1-5) and strategies (1-3). + and – within parentheses indicate examples of positive or negative implementation of the governance principle. Questions are available in Appendix 1 and 2.

Requirement/Strategy	Topics covered in interview questions	Interview Questions	Survey Questions
Providing information (R1)	-Participants share experiences where challenges have come directly from poor information sharing (-) -Participants express value in oysters and their related processes (+) -Participants share how more oyster education could benefit the community (+)	1, 9, 11, 12	5, 6, 7
Dealing with conflict (R2)	-Participants discuss conflict with institutions (due to communication, uncertainty, interpersonal) (-) -Participants share about past conflict that has been resolved (+)	1, 10, 12	5, 7, 8, 9
Inducing rule compliance (R3)	-Participants discuss experiences where rule compliance has been difficult (-) or has led to positive outcomes (+) -Participants discuss opportunities for enhancing rule compliance (+)	12, 13, 14	5, 8
Providing	-Organizations provide opportunities for technological,	12, 14	5, 8

infrastructure (R4)	knowledge, or regulation advancement (+) -Participants share where infrastructure is lacking/causing problems (-)		
Being prepared for change (R5)	-Participants discuss stopping or selling their oyster farm due to challenges (-) -Participants share that they have experienced climate or environmental change -Participants mention strategies that they implemented in their activities to mitigate environmental change (+) -Participants have income opportunities outside of the industry (+); if they have not considered alternate plans (-)	7, 15, 16a, 17, 18	5, 9, 10
Analytic deliberation (S1)	-Participants share whether they work or could work with other stakeholders (in any capacity) (+) -Participants share ideas they would like to learn about and/or implement that could offset challenges (+)	16b	
Nesting (S2)	-A lack of nesting in institutions has caused or exacerbated a challenge (-) -Identification of having nested institutions that could correct challenges (+)	1, 14, 17b, 17c	
Institutional variety (S3)	-Opportunities to increase institutional involvement across scales to correct challenges (+)	14, 16b, 17b, 17c	

3.2.4 Surveys

One stakeholder group was difficult to arrange interviews with, the wild oyster harvesters. This group is insular and has a history of mistrust with resource managers and scientists (R. Grice, pers. comm.). In order to meet with them to gain their perceptions, the interview manual was modified to a 10-question survey (Appendix 2) and distributed to wild harvesters during the Alabama oyster season at the Alabama Marine Resources Division Oyster Management Station (the Mississippi oyster season had been closed since 2019 at the time of this research project; Pruett et al. 2024). Harvesters who completed the survey received a nominal financial award ($20 USD) to incentivize participation. Similar to the previous interviews, the modified surveys were coded for interpretation (Table 3.2).

3.3 Results

3.3.1 Demographics

Sixty-two interviews and 26 surveys were completed throughout 2023-24. Interviews ranged in length from 15 minutes to 2.5 hours. For interview respondents, birth years ranged from 1946-1999 with an average of 1975. One interview respondent did not answer questions but rather provided an anecdote of their experiences in the oyster industry throughout the years, thus their information is not included in Figure 3.1. For survey respondents, birth years ranged from 1944-2000, with an average of 1975, indicating similar age ranges across response types.

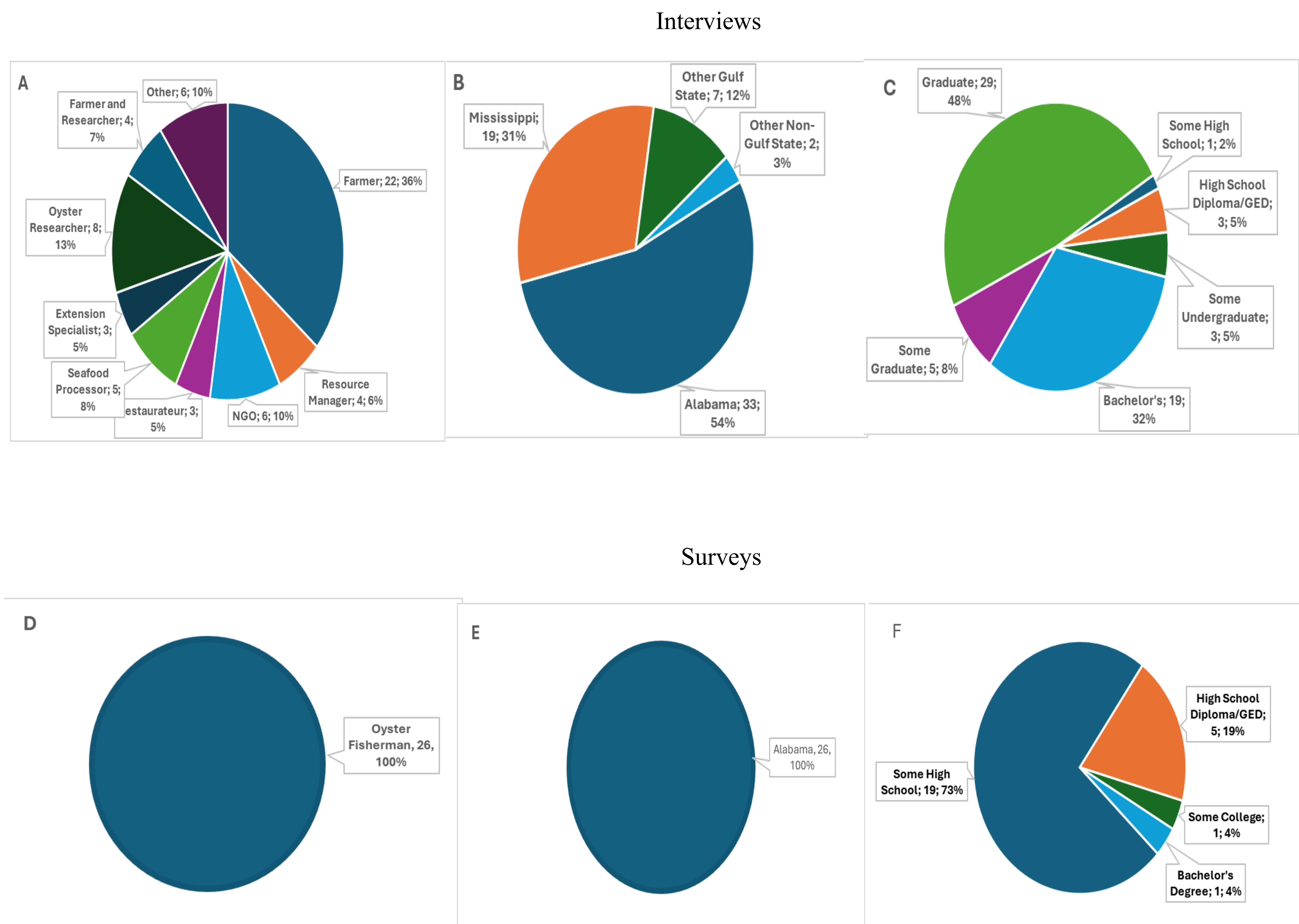


Figure 3.1. Demographic breakdown of interview and survey respondents: (A and D) stakeholder type; (B and E) oyster work location; and (C and F) education level.

3.3.2 Adaptive Governance

3.3.2.1 Providing Information (R1)

Systems that exhibit adaptive governance include stakeholders and entities that accurately provide information about the resource, its management, and the human-environment interactions that affect it (Dietz 2003). Within the Alabama and Mississippi oyster aquaculture industries, stakeholders perceived that information is not accurately provided about oyster-related policies and their enforcement. Specifically, participants (n = 15) in Alabama expressed that there were communication gaps with the main regulating agency, the Alabama Department of Public Health. These participants requested more information when different regulations on various topics were changed or why. Specifically, respondents discussed time to temperature regulations, where harvested oysters must be on mechanized refrigeration within a specific amount of time. Further, participants wanted more information on how regulations might be enforced, how waters are divided into different areas for testing, what triggers water closures, and why the triggers were made different from those in Mississippi despite the fact that waters across both states exist in similar conditions. Farmers held a perception that while their regulations were strict compared to other states, the information to justify those regulations was lacking. According to one Alabama farmer,

"We compete with other states, too, and our laws are so much stricter. Like we have to have our oysters refrigerated within one hour of harvest, but in Mississippi they have like three hours. You know, it's not like *Vibrio* grows faster in Alabama."

Though stakeholders felt that communications on regulation decisions could be improved, they are knowledgeable about oysters and their many ecological benefits. Oysters can provide six different ecosystem services (Grabowski and Peterson 2007), yet are often considered for their economic value (Humphries et al. 2019). When asked to rank different ecosystem services based on their level of importance, participants ranked most services (water cleaning, food production, coastal protection, and habitat provision) as highly important, and shared their experiences and opinions from witnessing these services in action. However, many participants (n = 54, 88%), agreed or strongly agreed that there should be more educational opportunities about oysters and their ecosystem services. One participant shared a story about a child visiting their oyster farm, stating

"One of my students lived five miles from the coast and had never seen an oyster shucked before - they thought it was a rock."

Participants feel that if education about oysters is improved, then more people, especially non-coastal residents, will be more invested in the industry and its survival into the future.

3.3.2.2 Conflict Resolution (R2)

Much of the conflict occurring in the Alabama and Mississippi oyster industries occur outside of the interpersonal or inter-institutional level. The majority of challenges experienced or perceived by participants are actually environmental, such as water quality issues, extreme weather events, and oyster predators. Thirty-three participants, including 14 farmers, shared their main challenges within the industry as environmental (Table 3.3). These issues can limit oyster production and harvest, therefore negatively impacting oyster producers' livelihoods and inhibit oyster restoration success.

Table 3.3. Types of environmental challenges indicated by interview respondents.

Challenge	**Frequency (n)**	**Percent (%)**
Freshwater influx (reducing salinity)	15	45
Pollution	7	21
Storms	7	21

Oyster predators	6	18
Climate change	6	18
Excess sediments	4	12
Rising water temperatures	4	12
Hypoxia	4	12
“Weather issues”	4	12
Droughts	3	9
“Nature itself”	2	6
Natural disasters	1	3
Harmful algal blooms	1	3
Oyster disease	1	3

This is not to say that interpersonal conflict does not exist within the oyster industry. Multiple stakeholder types described conflict between themselves, especially between resource managers, oyster farmers, oyster harvesters, and state regulators. Some (n = 16, 26%) of these conflicts stem from miscommunication about regulations and how they are implemented, as discussed previously. This miscommunication can lead to conflict if oyster farmers or harvesters unknowingly violate regulations, resulting in operations shut down or confiscated oysters and therefore lost profits. Similarly, conflict exists between oyster harvesters and resource managers, as harvesters perceive that managers unduly restrict their access and ability to harvest oysters. Meetings between the two groups have been contentious as a result, with one harvester believing that

“I ain’t never seen them [the state] out there catching oysters, but they’re making decisions for us when they don’t know.”

Other conflict was reported between some oyster farmers and organizations performing coastal restoration projects, such as marsh and shoreline restoration. Four Alabama farmers shared how they witnessed excess sediment in the water column during these projects, and how they perceived the sediment to cause mortality on their farms. The farmers shared that when they tried to communicate with the organizations performing the coastal work, that "they had no empathy and said it couldn't be them." These incidents cause frustration and mistrust between these two groups.

Participants, specifically farmers, (n = 6, 9.8%) shared that their most successful methods to resolve these conflicts revolve around litigation. As stated by one participant, "It took three years and a lawsuit threat to get my permits approved," and another stated "It took five years to settle [another case] for farmers to get paid on insurance." Participants shared their desire for increased communication and collaboration across stakeholder groups to help prevent and resolve conflicts and to address problems affecting the industry directly. One farmer currently feels that: "We have no recourse to get someone to listen and pay attention."

3.3.2.3 Inducing Rule Compliance (R3)

Despite the conflict that arises in the oyster industry from uncertain rules and regulations, some rules are perceived positively across states and stakeholder groups. The first of these is the traceability and food safety procedures in place to prevent foodborne illness. Participants, especially farmers, recognize the importance of these types of regulations despite the communication issues and inconsistencies between states as they keep oyster consumers safe and keep consumer confidence in their product high. According to one Alabama participant,

"I think they [the state] do a great job of testing and shutting us down when the water isn't safe. We want to be able to tell people out of state that Alabama seafood is just as safe as New England, so I give them [the state] props for that."

Both Mississippi and Alabama have unique, positively-perceived rules and regulations. In Mississippi, oyster farmers and harvesters (when wild harvest season is open) do not have to sell their oysters to processors, they can sell directly to consumers. This eliminates a “middle-man” step and allows Mississippi producers to earn a better price for their oysters. In Alabama, oysters must be sold to seafood processors before consumers. Mississippi farmers are very positive about this rule and do not want it to change, and some Alabama farmers wish that their state had a similar system. Some farmers in Alabama have reported that they became licensed seafood processors themselves in order to navigate this requirement.

In Alabama, resource managers from the Alabama Department of Conservation and Natural Resources Marine Resources Division (AMRD) developed a grid system for their oyster reefs to assist with oyster harvest. This system requires harvesters to report which grid quadrant they caught oysters from so that managers can keep track of which parts of the reef are harvested more heavily. Through this system, managers can close parts of the reef during harvest season to ensure the harvest pressure is equal across the reef. Both Alabama oyster farmers and researchers perceive this system to be a positive example of oyster management, yet some harvesters (n = 3, 11%) disagree. They feel this system restricts their ability to harvest and that they should be able to harvest across the reefs, only stopping once they reach the overall harvest quota. As stated by one harvester,

“If there’s a quota, there shouldn’t be a limit. If it’s open for a set period of time, then there should be a limit. But if it’s just a quota then we should be able to go and harvest until we reach that quota.”

Some rules, however, are less effective, according to participants. In both Mississippi and Alabama, some participants shared that many of the aquaculture regulations were copied from the wild harvest rules. These include an inability to harvest oysters at night and that oyster shell cannot be loose in a fisherman’s boat, it must be returned to the reef. For wild oyster harvest, these laws are thought to prevent oyster poaching and to ensure oyster shell returns to the water to replenish oyster reefs. However, oysters produced for oyster aquaculture are private property, not state property, so these rules do not fully apply to oyster farmers yet can negatively impact their ability to work their farms and harvest their oysters.

Other regulations are complicated and difficult and/or time-consuming to follow. This is especially true for permitting requirements for oyster aquaculture. In the State of Alabama, would-be farmers need approval from six state and federal agencies and divisions before they can begin farming. This process can take over one year to complete and can inhibit new farmers from joining the industry. However, as discussed below, there is some infrastructure that could help circumvent these issues.

3.3.2.4 Providing Infrastructure (R4)

Many participants, especially oyster farmers, expressed desire for various infrastructure types to help improve or bring awareness to their industry. One is in the form of governmental programming/assistance, such as marketing programs and crop insurance. While Alabama and Mississippi do provide some assistance for marketing, farmers expressed the desire for increased visibility for their product. Increased visibility could help inform people about locally-produced oysters and about the oyster aquaculture industry in general, potentially increasing interest in the industry. One farmer stated,

“Other states have an oyster trail and it’s super successful. All I need to do for the state is to bless it and cough up some money for a website. So many people are curious about the process, but it’s so hard for us to do a big tourism push while working. It wouldn’t be that expensive. Just some sort of oyster trail like they have in New England or the Carolinas. I’ve got a whole template - if you visit four stops you get a hat, we could centralize merch across farms, stuff like that. We’re missing out by not having one. I’ve got a whole bunch of chamber of commerce names ready, we just need someone to take the jump.”

Similarly, there is one program available for crop insurance, implemented by the U.S. Department of Agriculture, the federal agency tasked with managing commercial food production and safety in the United States. This program is limited to established aquaculture farms as it requires a minimum of four years' worth of operational and sales records (USDA 2024). Thus, farmers expressed the need for inclusive crop insurance provided at multiple levels other than federal.

Physical infrastructure that were identified as needed by participants included more aquaculture parks, physical structures to protect these parks, and aquaculture gear designed specifically for Gulf conditions. Aquaculture parks are pre-permitted waters where farmers can operate their farms, reducing the time farmers need to obtain all necessary permits on their own. Both Alabama and Mississippi have established aquaculture parks, but farmers desire more to facilitate new farms or farm expansion. Mississippi farmers expressed desire for protection for their aquaculture park in the form of bulkheads or breakwaters. The Deer Island Aquaculture Park is located south of Deer Island, MS (MDMR 2024), and does not have natural protection against wave action, thus making farming difficult, according to farmers. Installing bulkheads or breakwaters near this park could increase the safety and ease of oyster aquaculture practices for these farmers. Finally, the gear used by oyster farmers is expensive, and was designed in other parts of the world that do not experience the same conditions, such as high temperatures, varying salinities, and changing environmental conditions that Gulf waters do. Gulf farmers (n = 8) express that their gear frequently breaks and/or gets covered in biofouling organisms, such as algae and barnacles, that can inhibit oyster growth. Thus, farmers spend a lot of time fixing and cleaning their gear, which takes time and resources, as aquaculture gear is expensive. Some farmers expressed that Gulf-designed gear would be beneficial to their business practices by potentially reducing overhead costs. Though the gear would be designed by private companies or entrepreneurs, governance could assist by funding gear design projects.

3.3.2.5 Being Prepared for Change (R5)

It is important to consider how new information, especially relating to climate change, could affect the Alabama and Mississippi oyster industries. Participants were asked about how they have experienced and responded to climate change in their work relating to oysters. Responses revealed a dichotomy between participants, especially farmers - half (n = 11) indicated that they had seen the effects of climate change, while the other half (n = 11) shared that they had not, and two farmers were uncertain. Those who indicated that they were unaffected also indicated they had not been in the industry long enough (1-5 years) to see the effects. Similarly, these participants shared a lack of concern about climate change impacts in the near future because they view it as a long-term issue. Further, they credit climate change to natural, cyclical patterns and that “oysters have been dealing with these issues for centuries and are still here, so what can we do?”

Another dichotomy for oyster farmers exists between those who would continue in the industry should another major natural disaster, such as a hurricane on the same level as Hurricane Katrina, were to occur. Ten farmers indicated they would rebuild, while five would not, with the remaining farmers uncertain. Those that would rebuild cited a love for the industry and the high demand for oysters, stating, “If you’re able to raise one oyster to maturity, it’s sold. Demand is through the roof right now so there’s plenty of possibility for business if the oysters can survive.” Those that would not rebuild discussed issues with material and labor cost, especially with a lack of comprehensive insurance plans or timely disaster recovery payouts.

Oyster harvesters shared similar views to farmers. Only 4 out of 26 respondents indicated that they viewed environmental change to be a major issue. One harvester stated, “Oysters are only bothered by fresh water,” and two others shared concerns over hurricanes. However, when interview participants were asked about the longevity of the oyster industry, respondents (n = 18) shared concerns for the wild harvesters, stating that group of stakeholders is the most at risk to losing their ability to harvest oysters due to industry issues, such as closures, low oyster prices, and environmental hazards, among others. Oyster harvesters disagreed with this sentiment, as when asked if they plan on continuing harvesting oysters, many (n = 22) stated yes, with a few stating "until the day they die." Only a few (n = 2) stated that they would not, citing health issues or issues relating to aging. Two respondents were unsure if they would remain in the industry over the next 5-10 years.

3.3.3 Strategies

3.3.3.1 Analytic Deliberation (S1)

One key issue stems from a lack of analytical deliberation, or the communication and/or collaboration across different stakeholder groups. This is potentially the reason behind differing perceptions over climate change impacts across groups, as discussed previously. Though research indicates that a changing climate could negatively impact oyster production, it is perceived more strongly in some stakeholder groups than others, such as oyster researchers compared to oyster harvesters. This may inhibit communication and strategy building between these two groups if perceptions are not brought to the same page.

3.3.3.2 Nesting (S2) and Institutional Variety (S3)

Some of the above issues stem from a lack of adaptive governance strategies in the Alabama and Mississippi oyster industries, especially nesting and institutional variety, which refer to the scales and types of institutions involved in management. For example, some federal agencies, such as the U.S. Food and Drug Administration, the U.S. Army Corps of Engineers, and the U.S. Coast Guard, are involved in food safety regulation guidelines and aquaculture operation permitting and implementation. However, once an operation is underway in Mississippi and Alabama, the Mississippi Department of Marine Resources, the Alabama Department of Conservation and Natural Resources, and the Alabama Department of Public Health develop and enforce regulations relating to oysters. Some Gulf-scale committees exist, such as the Gulf States Marine Fisheries Commission, but this group is only advisory and does not create or implement regulations (P.L. 81-66 1949, Chapter 2). Having policy-making power contained to the state level can be beneficial to limit cross-scale confusion and complicated bureaucracy, but can make responding to cross-scale hazards and events like environmental disasters difficult.

Table 3.4. A summary of the results where + or - in Findings correspond to interview/survey topics in Table 3.2.

Requirement (R) or Strategy (S)	**Positive Implementation Findings**	**Negative Implementation Findings**
Providing information (R1)	Stakeholders are aware of ecological services oysters provide (+)	Information is not adequately provided about regulations (-)
Dealing with conflict (R2)		Conflict primarily occurs between oyster-producing stakeholders and their environment (-) Interpersonal conflict occurs between oyster producers and resource managers (-) Only one method for resolving conflict identified (litigation) (-)
Inducing rule compliance (R3)	Food safety and traceability regulations are perceived positively by stakeholders (+)	Aquaculture regulations in both states are adapted from wild harvest yet do not fully apply due to production differences (-) Aquaculture permitting is perceived as a long and complicated process (-)
Providing		Stakeholders, especially farmers,

infrastructure (R4)		want physical infrastructure in terms of aquaculture parks and programming such as industry awareness and insurance (-)
Being prepared for change (R5)	Most farmers and harvesters would attempt to continue in the industry even after a major environmental hazard (+)	Half of farmers and few harvesters perceive climate/environmental change as a major issue and thus may not have action plans or resources available (-)
Analytic deliberation (S1)		A lack of communication across groups leads to a lack of consensus on climate change (-)
Nesting (S2)	Oyster production management exists at the state level with little federal or local input (+/-)	
Institutional variety (S3)	One nationwide regulatory body exists (ISSC) (+)	Institutional types are state resource management agencies; one Gulf scale advisory board exists (-)

3.4 Discussion

Interviewing and surveying oyster stakeholders from Mississippi and Alabama identified many challenges throughout the oyster production industry which could negatively affect the industry's resiliency as per the adaptive governance framework. These include confusing or limited communication about pertinent regulations; environmental and interpersonal conflict with limited conflict resolution opportunities; limited rule compliance in aquaculture due to inapplicable or complicated regulations; a lack of both physical and programming infrastructure; a potential lack of preparation for change due to unperceived environmental changes; and nesting existing across one scale. Altogether, these results indicate a system with low resilience to future hazards and climate change based on the adaptive governance framework (Table 3.4).

As stated previously, the adaptive governance framework has been applied to different marine socio-ecological systems worldwide (Nunan 2010, Österblom and Folke 2013, Datta and

Chaffin 2022). However, due to the complexity of fishery systems, including their size and differences in power-sharing, studies have indicated that adaptive governance implementation is difficult (Sharma-Wallace et al. 2018, Quimby 2023). This research represents the first instance where adaptive governance framework has been applied to the oyster fishery of Mississippi and Alabama and its challenges. Utilizing the framework successfully identified many challenges causing decreased resiliency in this industry. However, in the northern Gulf of Mexico oyster system, processes in one state affect oysters in another, and differing agencies, policies and management techniques across states makes overcoming challenges difficult as discussed in Chapter 2. Thus, effective implementation of adaptive governance is likely limited in this system as it is in others (Sharma-Wallace et al. 2018, Quimby 2023).

One method to curb this complexity is having some federal or Gulf-wide oversight into regulation creation and enforcement, which could improve rule consistency and management across states. The ISSC is an effective example of this for food safety at the federal level, and a similar system for estuarine health could be beneficial. However, this strategy may not be possible due to the states' inherent responsibility over their resources per the U.S. Constitution. Similarly, Gulf oyster producers may not want additional regional or federal oversight and regulations (Craig and Danley 2017, Seetaram et al. 2019, Moorman et al. 2025).

As discussed earlier, half of surveyed farmers were unconcerned about climate change in the short term while oyster researchers shared the most concern about the potential negative impacts. A similar dichotomy in differing perceptions were reported for oyster producers in North Carolina (Deason et al. 2014) and in Canada (Steeves and Filgueira 2019). A lack of concern over perceived climate change impacts could hinder efforts to proactively manage for future climate conditions, so it is important for these two groups to work together to collect and analyze environmental variables at farms across both states. This type of collaborative research involving farmers is already being completed in the Gulf and elsewhere (Parker and Bricker 2020, Walton and Swann 2021) and could inform both groups about actual versus possible change.

Environmental challenges such as freshwater influx, pollution, storms, and others cause the most conflict for oyster producers both in our study and in British Columbia, Canada (Mallows and Shaw 2023). However, there is not much that individual stakeholders can do to correct these issues because of their nature; collective groups like agencies and states can invest in improved watershed practices, but this is limited on an individual level. Further, oyster harvesters and farmers may experience other limitations, such as regulations or financial constraints (see Chapter 4). They currently can only mitigate the effects of these conditions, but researching actual environmental conditions may help develop new strategies and increase environmental stewardship among oyster producers (Johnson et al. 2019, Paget et al. 2016).

Environmental change and natural hazards have limited harvesters' ability to commercially fish oysters over time by reducing habitat suitability and causing mortality events (Gledhill et al. 2020). However, harvesters did not perceive environmental challenges to be an issue to oyster harvest. It is uncertain why this group holds these perceptions, so more research should be conducted with this group to better understand their environmental perceptions and local ecological knowledge. It would benefit both resource managers and oyster harvesters to communicate their ecological knowledge to determine how their perceptions of the local environment compares. If each group has more understanding of the other group's perceptions and knowledge about potential ecological processes, they may have more collaborative success developing different management decisions, such as specific locations for oyster restoration and harvest limits, than they are now (Tidball and Krasny 2011, Deason et al. 2014, Brown et al. 2021, North et al. 2024).

Increasing communication and collaboration may also spark new ideas for solutions to overcome challenges. Specifically, participants shared many ideas for how their states could help improve the industry, such as farmers wanting marketing and insurance, and harvesters wanting more oyster planting efforts. These are all cost-heavy endeavors and may require additional policy and resources and thus may not be feasible to readily implement. Creating working groups with multiple institutions and stakeholder types, or enhancing communication between existing groups, could help develop alternate solutions or working plans to implement these projects, like the one in Maryland, USA discussed by North et al. (2024). One example of a newly-formed working group is the Alabama-Mississippi Oyster Community of Practice, which worked to build communication and collaboration across stakeholder groups (Sower et al. 2025; Chapter 1).

Many of the issues relating to oyster aquaculture in Mississippi and Alabama come from the industry's newness in the northern Gulf of Mexico. Alabama was the first Gulf state to produce oysters via off-bottom oyster aquaculture in 2009, with Mississippi following in 2019 (Walton and Swann 2021). Because of its newness, states may have not yet found the most effective regulation strategy, resulting in rules copied from wild harvest that do not apply to aquaculture production as discussed in Chapter 2. To account for this, state policy makers and regulators would benefit from communicating and designing policy directly with oyster farmers (Brown et al. 2021). Efforts such as these could help to increase the resiliency of the oyster producing industry by creating policy and strategies specifically tailored to each production type.

Finally, this study can help with resource challenges outside of the Gulf of Mexico or oyster management. This study highlights challenges with new industries within a socio-ecological system specifically relating to regulations and infrastructure challenges. We believe that the solutions to many of these challenges - communication and collaboration across stakeholder groups - can be utilized across resource systems. Societies with tightly linked connections to their environment and/or a natural resource that are affected by natural and manmade hazards would benefit from inclusive decision-making and management, which could inherently increase the system's flexibility and responses to hazards, thus increasing their resiliency (Österblom and Folke 2013).

3.5 Conclusions

This study examined the requirements and strategies of the adaptive governance framework in the Mississippi and Alabama oyster industries to determine their resilience, especially to climate change. This study identified numerous challenges throughout the industry relating to regulations and environmental changes. Though there are many challenges currently within the Mississippi and Alabama oyster production industries, there are many potential strategies and solutions to correct these challenges. Many stem from increasing communication and collaboration across stakeholder groups. Through increased communication and collaboration, entities can 1) provide stakeholders with accurate information about oysters and their related regulations; 2) help resolve and prevent conflict between user groups; 3) induce effective rule compliance by creating production-specific policy and explaining its importance; 4) developing and implementing beneficial infrastructure; and 5) collecting, analyzing, and sharing information about potential impacts and environmental changes and developing mitigation strategies.

Chapter 4: How are Oyster Farmers and Harvesters Responding to Climate Change in the Gulf of Mexico? Using Climate Scenarios to Communicate Climate Modeling Predictions

Abstract

Oysters in the U.S. Gulf of Mexico are vulnerable to climate change related alterations and disturbances as they are tightly linked to their surrounding environmental processes. However, mitigation strategies to address the effects of climate change are uncertain within oyster production industries, including wild harvest and oyster aquaculture. In this study, short, narrative-style climate scenarios were used to communicate plausible ecological futures in an accessible way to stakeholders across a wide range of educational and cultural backgrounds from the Mississippi Sound and Mobile Bay. Scenarios were generated using simulations from an Earth system model, the Community Earth System Model 2 Large Ensemble, and focus on different environmental variables and how they may change over time. Future projections for variables affecting key aquatic conditions for oyster production were analyzed, including net primary productivity, omega aragonite, salinity regimes, and temperature over the next three decades. Results predicted higher salinities and water temperature and lower net primary productivity and omega aragonite, indicating stressful conditions for oysters. Scientific illustrations depicting these conditions were distributed to oyster farmers and oyster harvesters from Alabama and Mississippi during fall 2024-spring 2025 to communicate future impacts. Scenarios were accompanied by a 10-question survey to gauge what resources and techniques participants would utilize to respond to environmental change based on available strategies, as well as stakeholder perception towards environmental change. Results indicate that both oyster farmers and harvesters may have limited response strategies due to regulations, financial

constraints, and cultural environmental connections, such as their longstanding tradition of harvesting oysters throughout familial generations. Without better access to various mitigation strategies, oyster production in Alabama and Mississippi is at risk to climate change in the near future.

4.1 Introduction

Climate change and its effects on resources within socio-ecological systems is a topic of concern throughout the northern Gulf of Mexico, hereafter referred to as "the Gulf" (Lehrter et al. 2017, Laurent et al. 2018). This is especially true in the oyster industry, as oyster populations have been declining long-term in the region and are susceptible to further decline from changing environmental conditions and extreme natural hazards (Jones et al. 2019, McFarland et al. 2022). Several oyster-relevant environmental variables may be influenced by climate change: sea surface temperatures and salinity may increase, while net primary productivity (food availability) and the saturation state of aragonite may decrease (Feely et al. 2018, Czajka et al. 2025). Further, it's been indicated that oysters may be particularly vulnerable to the combination of these factors that could negatively impact their growth (Table 4.1; Powell et al. 2004, Plutchak et al. 2010, Waldbusser et al. 2010, Lowe et al. 2017). Oysters have been harvested in the Gulf for generations and they represent an important cultural connection between people and their environment (Vanderkooy 2012, Dalrymple et al. 2021). Thus, the loss of oysters and the oyster industry could have many negative consequences throughout the region.

Currently, there are two types of oyster production in the Gulf: wild oyster harvest and oyster aquaculture. Wild oyster harvest is the traditional method of oyster production, in which fishermen collect natural or planted oysters from the water bottom. Oyster aquaculture is a more controlled method of oyster production, in which aquaculturists (hereafter referred to as “farmers”) monitor and grow oysters in cages or bags that are off or on the water bottom, referred to as off-bottom and on-bottom, respectively (Walton et al. 2013). Off-bottom oyster aquaculture is relatively new to the Gulf region, starting in Alabama in 2009 (Walton and Swann 2021).

In order to predict the effects of climate change on oyster production in the Gulf, future potential environmental changes need to be identified. Climate models are useful tools to help predict changing environmental variables in a region over time. These tools are especially important as climate change progresses, helping natural resource managers and stakeholders in tightly-linked socio-ecological systems prepare for change. However, communicating climate modeling results to non-scientific audiences can be difficult, especially because of personal or cultural beliefs surrounding climate change (Schneider 2012, Carlton and Jacobson 2016).

One method to simplify and communicate modeling data is through climate scenarios. Climate scenarios are defined here as short narratives with illustrations that read like simple stories, describing plausible ecological futures in a way that is accessible to stakeholders from a wide range of educational and cultural backgrounds (Weber 2010). Climate scenarios may also be used to help identify mitigation strategies, as well as inform policy makers and resource managers about potential climate effects on a resource (Garb et al. 2008, Morris et al. 2024). Moezzi et al. (2017) explored numerous studies in their review of storytelling in energy and climate change research yet found that forms of narration and illustration like climate scenarios were underrepresented. To our knowledge, this study is the first of its kind to use this method to communicate and study climate change effects within an oyster socio-ecological system.

For this study, we modeled environmental conditions in the Mississippi Sound and Mobile Bay over the next thirty years using an Earth system model developed at the National

Center for Atmospheric Research, the Community Earth System Model version 2 (CESM2; Danabasoglu et al. 2020). We focused on these two regions because both Mississippi and Alabama oyster harvests have experienced long-term decreased population numbers over past decades (Dalrymple et al. 2021, Pruett et al. 2024). Model results were communicated to oyster farmers and harvesters via climate scenarios alongside surveys about how oyster producers perceive environmental change and what strategies they can implement to mitigate it. The objective of this study is to explore and identify which mitigation strategies may be available to each production group, and what are the limitations for each group using these strategies. The analysis of these responses was intended to provide an initial evaluation of the resilience of the oyster industry to future climate change.

4.2 Materials and Methods

4.2.1 Climate Modeling

Environmental conditions of the Mobile Bay and Mississippi Sound areas were projected 30 years into the future using the CESM2 large ensemble (CESM2-LE; Rodgers et al. 2021). The CESM2-LE is a publicly available collection of CESM2 transient climate simulations; each simulation is an "ensemble member." We used the 50 ensemble members that follow the Coupled Model Intercomparison Protocol phase 6 (CMIP6) forcing. All CESM2-LE ensemble members follow historical (1850-2015) forcing, then future forcing under a moderately high emissions scenario, Shared Societal Pathway 3-7.0 (SSP3-7.0). While the forcing is the same, small (10-14°C) differences in air temperature at model initialization produce a spread in the timing of natural ("internal") climate variability in the model. By using a large ensemble, we can separate internal climate variability (the spread of ensemble members) from the radiative-forced response (ensemble mean; see Deser et al. 2020 for more details).

We focused our analysis on ensemble mean changes in four environmental variables that influence oyster physiology: salinity, temperature, Ω aragonite, and net primary productivity (NPP) (Table 4.1). Salinity and temperature directly affect oyster physiology, growth, and respiration; Ω aragonite affects how larval oysters form their initial shells; and NPP represents the amount of food available to oysters. Each of these factors are expected to be shift due to climate change (Table 4.1). CESM2-LE simulations were run under the SSP3-7.0 forcing for 50 simulations, a moderately high emissions scenario under lenient climate mitigation policies (Shiogama et al. 2023). After 30 years, results indicate NPP decreasing by ~2 mmol m^{-2} d^{-1}, Ω aragonite decreasing by ~0.6, water temperatures increasing by 1°C, and salinities increasing by 0.5 ppt (Figure 4.1), and were used to craft climate scenarios. Optimal ranges for growth and survivability fluctuate for oysters depending on their local estuarine conditions. Fugua and Brooke (2025) identified a salinity range of 10-16 ppt for highest survival for oysters in northwest Florida, and Lowe et al. (2017) found optimal growth between temperatures of 20-26.3°C for oysters in Louisiana. It is important to note that while individually these values may still fall within the normal expected range for oysters, their combined effects as long-term stressors are expected to lead to increased mortality in oysters and decreased oyster production (Soletchnik et al. 2007, Lowe et al. 2017). Further, these changes may also increase the prevalence of oyster predators, such as oyster drill, and disease, such as dermo, which can reduce oyster harvests (Albright et al. 2007, Kimbro et al. 2017).

Table 4.1: Key environmental factors used in modeling and their potential relationships to oysters.

Environmental Factor	**Climate Impact/Effect on Oysters**	**Source**
Net primary	Decreased phytoplankton availability therefore	Barton et al. 2012

productivity (NPP)	decreases growth and/or survivability in food-limited systems	Plutchak et al. 2010
Ω aragonite	Decreased saturation state of aragonite, negatively influencing larval oysters' ability to synthesize their shells	Barton et al. 2012 Newton and Klinger 2023 Waldbusser et al. 2010
Salinity	Increased salinities near or exceeding their thresholds can influence growth and increase mortality and can increase predator abundance	Zachary and Haven 1973 Lowe et al. 2017
Temperature	Increased temperatures can cause slower growth but can also increase mortality depending on their optimal range	Powell et al. 2004 Lowe et al. 2017

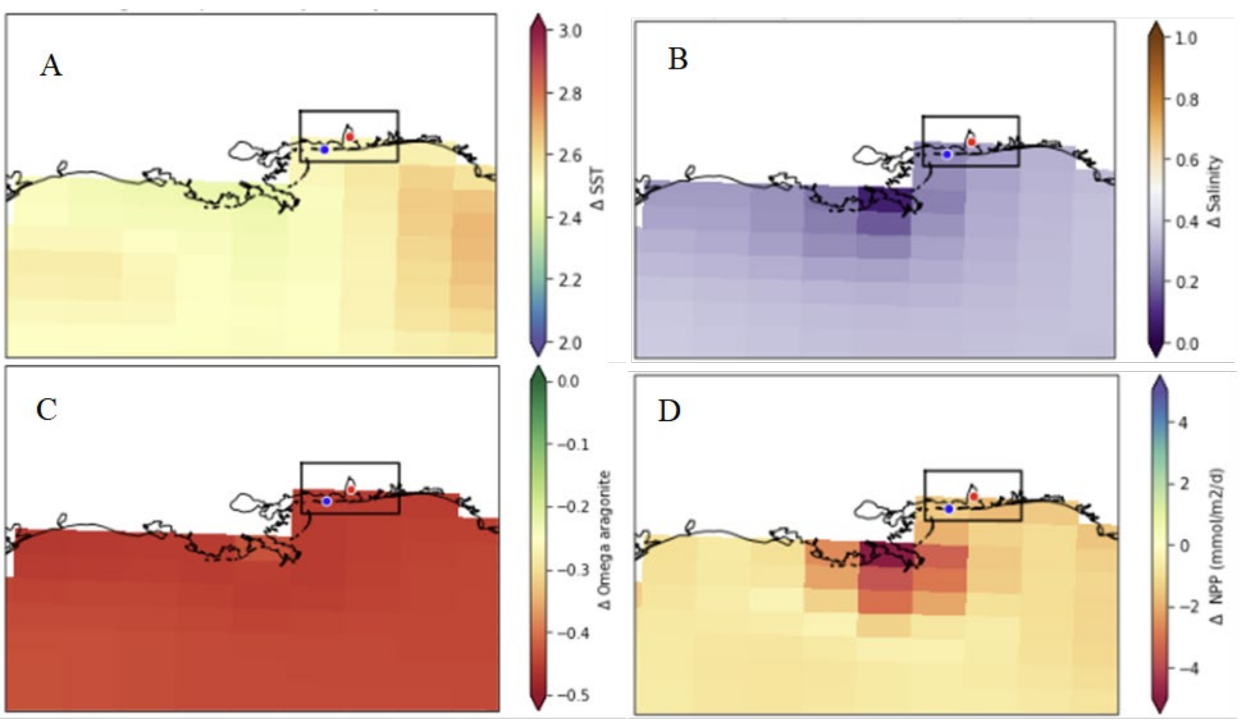


Figure 4.1. Community Earth System Model 2 results in the Mississippi Sound (blue dot) and Mobile Bay (red dot) over the next thirty years for average changes in (A) sea surface temperature (SST), (B) salinity, (C) the saturation state (Ω) for aragonite, and (D) net primary productivity (NPP).

4.2.2 Climate Scenarios

Scientific illustration is an effective tool to communicate information via visual references (Cerviño et al. 2015). We used scientific illustration to create two different scenarios, one each for farmers and harvesters. Each scenario depicts environmental conditions both in the present day and 30 years into the future, representing how changes predicted by the climate model could impact oysters. Future changes include less oysters in the water, lower oyster productivity, less aquatic biodiversity, increased oyster predation, and fewer farmers and harvesters in the water (Appendices 3 & 4). While the illustrations may depict a worse-case scenario than predicted by the model, it is important to show clear, sizeable changes in habitat quality as a potential result of climate change. Both scenarios were paired with plain language summaries describing the changes within each illustration for participants to review before taking the associated survey.

4.2.3 Survey Creation & Implementation

Both oyster farmers and oyster harvesters are potentially impacted by climate change as their professions depend heavily on the environment around them. However, they may experience or perceive changes differently, as seen in Chapter 3; thus surveys differed between farmers and harvesters.

Farmer surveys focused on identifying strategies they can implement to mitigate environmental impacts, whether they monitor environmental conditions on their farms, and how they perceive access to environmental monitoring data in the region based on farm ownership/operation time (Appendix 5). Demographic information was not collected for farmers during this study as it was already collected during previous research (see Chapter 3). Strategies to mitigate mortalities, especially related to Sudden Unusual Mortality Syndrome (SUMS), were adapted from an oyster mortality workshop to test for feasibility (Virginia Institute of Marine Science (VIMS) 2024). Though the VIMS (2024) report specifically references SUMS related mortalities, many of the applied strategies discussed within the report are applicable as potential options for oyster farmers experiencing various environmental stressors. Strategies from the report include moving farm equipment to a new location; decreasing oyster stocking density; minimizing handling during stressful conditions; stocking with both diploid and triploid oysters rather than just triploid; and harvesting triploids before spring/summer. Surveys were created via Qualtrics and sent to Mississippi and Alabama farmers (n = 21) identified from the Alabama-Mississippi Oyster Community of Practice participant list (Sower et al. 2025) throughout fall 2024.

Harvester surveys focused on gathering information related to environmental change perceptions, possible alternate strategies, and environmental knowledge. Our analyses examined how their demographic information, such as education and political leaning, may relate to these perceptions (Appendix 6). Although similar demographic information was previously collected in Chapter 3, we took this opportunity to learn more about this stakeholder group, as they can be difficult to contact and involve in research. Surveys were distributed in person at the Alabama Department of Conservation and Natural Resources Oyster Management Station near Dauphin Island, Alabama in November 2024, and participants received a nominal financial award ($20 USD) for completing surveys (see Chapter 3 for more information). Surveys were only distributed to Alabama harvesters as the Mississippi oyster harvest was only experimentally opened in the 2024-2025 season after a multi-year closure starting in 2019 (Pruett and Otts 2021). Both farmer and harvester survey responses were collected and have been kept confidential as per Auburn University's Institutional Review Board (#22-445 EX 2210) requirements.

4.3 Results

4.3.1 Oyster Farmers

A total of sixteen oyster farmer responses were recorded with ten completed surveys. Six of the respondents had owned and/or operated their farms for six or more years, while the other four farmers had each owned/operated their farms for one to five years. Eight out of ten farmers believed that the depicted environmental changes based on the combined environmental effects from the model could negatively impact their farm operations, while one said it would not, and the other was unsure.

4.3.1.1 Mitigation Strategies

Results found varying ability for farmers to implement the available mitigation strategies (Table 4.2). Two out of 10 farmers said they did not implement any of the suggested strategies from the workshop at the time of the survey (Appendix 5 question 4; VIMS 2024). The remaining eight farmers minimized handling during stressful conditions (n = 8), decreased stocking density (n = 7), and stocked both diploid and triploid oysters (n = 6). Three farmers said they harvested their triploids before spring/summer, and only one farmer was capable of moving their farm equipment to a new location. When asked how likely they would be to implement each strategy (Appendix 5 question 5), responses followed similar trends (Table 4.2).

Table 4.2. Likeliness of farmers implementing each mortality mitigation strategy.

Strategy	**Already Implementing (#)**	**Very Likely (#)**	**Likely (#)**	**Not Likely (#)**	**Cannot Implement (#)**
Moving farm	0	1	0	1	8
Decrease stocking density	0	3	4	1	2
Minimizing handling	1	5	3	0	1
Stocking both diploid	1	5	1	2	1

and triploid oysters					
Harvest triploids in spring/summer	1	1	3	5	0

Farmers were also asked what barriers they face to strategy implementation. Restrictive location options was the most-selected response (n = 4), followed by cost of relocating (n = 3) and the slower growth from diploid oysters (n = 3). Five farmers also selected other reasons that they cannot or would not implement these strategies, with two stating that the strategies are not yet needed, one stating old age, and one stating that none of the strategies are really viable without broodstock modification research. The final farmer did not provide a response. Other potential strategies that farmers currently implement include novel farm technology (n = 2), altering desiccation times (n = 2), and changing equipment positions within the water column (n = 1).

4.3.1.2 Environmental Monitoring Data

Nine out of ten farmers monitor environmental conditions on their farm, including water temperature, salinity, dissolved oxygen, turbidity, and pH (Table 4.3). Other environmental conditions monitored include water depth, wind velocity, the presence of animals and people, sunlight, and air temperature.

Table 4.3. Environmental conditions monitored by Mississippi and Alabama oyster farmers surveyed (n = 10).

Environmental Conditions	**# Farmers Monitoring (n)**
Temperature	8
Salinity	8
Dissolved oxygen	5
Turbidity	2

pH	1
Other	5

When asked whether farmers obtain environmental data from other sources, nine out of ten responded affirmatively. Farmers mostly (n = 6) obtain environmental data from local universities and oyster researchers. Five out of ten farmers also obtain data from state resource managers and Extension specialists, and four also rely on state regulatory agencies. Further, four farmers conduct their own environmental research and/or review environmental literature. Finally, one farmer relies on a local non-governmental organization, and one uses an Internet resource Ventusky.com (Ventusky 2025).

Finally, farmers were asked whether they felt they received or have access to environmental condition information, and if they felt that access could be improved. Most (n = 6) farmers feel that they do have enough access, while the remaining farmers stated they would like more access, especially relating to dissolved oxygen information and water dynamics and interactions within Mobile Bay. However, six farmers still feel that access could be improved, whether that be the resolution and quality of the data, data to help identify where oyster crops could be moved, and data that maps mortality events for farmers to identify risk areas.

4.3.2 Oyster Harvesters

Twenty-two oyster harvester surveys were completed in November 2024. Birth years ranged from 1955-2005 and education levels varied from 3rd grade to post-graduate degree. The majority of participants (n = 13) identified as Republican, while seven aligned with other political parties and two preferred not to answer.

When harvesters were asked if the effects of the modeled environmental changes could harm their oyster harvest in the future, most (n = 14) said yes, especially related to increased oyster predator presence. Seven said no and that their harvest would remain about the same and that past environmental changes had not had an effect on harvest. One was unsure, stating that harvest changes from year to year.

4.3.2.1 Mitigation Strategies

Harvesters were also asked about how they might prepare for environmental changes (Table 4.4). Five harvesters said they could not prepare in any way for these changes, while a majority (n = 14) shared their opinions on how they believed the state resource managers could help. These included planting more oysters, testing alternate harvesting practices, supplying funds to harvesters, and allowing harvesters to dredge the water bottom to kick up shell to uncover them from mud. Many respondents (n = 12) would remain in marine fields if they could not harvest oysters, through either shrimping, crabbing, or working in a shipyard.

Another strategy harvesters could use to continue harvesting oysters is to travel to another state. However, when Alabama harvesters were asked if they would travel to another state to harvest oysters if they no longer had the ability to do so in Alabama, the majority (n = 12) responded negatively. Most respondents did not provide a reason why, but those that did shared that they had a strong connection to the area and that they wanted to be able to harvest oysters in Alabama as they had been doing since they were children. Eight other harvesters said they would travel, mostly to Louisiana (n = 5), which boasts the largest oyster population in the Gulf.

A final strategy for harvesters is to start their own oyster off-bottom aquaculture operations. Though oysters produced via aquaculture methods face the same environmental stressors as wild harvested oysters, this method would allow harvesters to continue producing oysters should wild reefs close. Proponents of aquaculture in the Gulf have tried to incorporate more harvesters into off-bottom aquaculture, as it is thought to be a more consistent source of oyster production (Walton et al. 2013). When asked if harvesters would start or work on an oyster farm, the majority of respondents (n = 13) said they would not for a variety of reasons. Some harvesters (n = 2) stated that they were unfamiliar with the practice, while others (n = 3) stated that aquaculture was too expensive. Two others shared that they wanted to continue harvesting oysters the traditional way, and felt that aquaculture created competition. Only seven respondents said they would start an oyster farm, with one adding if it was all that was available.

Table 4.4. Mitigation strategies open to surveyed oyster harvesters (n = 22).

Strategy	**# Harvesters**
More state involvement	14
Traveling to another state to harvest oysters	8
Start an off-bottom aquaculture operation	7

4.3.2.2 Environmental Knowledge

Ocean acidification may affect Gulf oyster larvae (Waldbusser et al. 2010, Barton et al. 2012, Newton and Klinger 2023) and was thus included in climate modeling and scenario drafting. To test whether oyster harvesters were aware of this issue, they were asked if they had heard the term. Only one participant heard the term before and was the same participant with a graduate degree. None of the other participants were aware of the term.

4.4 Discussion

Preparing for potential environmental changes due to climate change is an important management strategy for a tightly-linked socio-ecological system like the Mississippi and Alabama oyster industries. This study suggests that both oyster farmers and oyster harvesters perceive that they have limited options to respond to a changing environment, which indicates low resilience to climate change.

4.4.1 Oyster Farmers

The VIMS (2024) meeting summary represents a best practice review for oyster farmers to mitigate mortality events based on multi-expert opinion and discussion. The document recommended five different strategies to offset oyster mortality that we applied to potential environmental changes; our study suggests that farmers are only able or willing to implement three of them (minimizing handling, stocking farms with both diploids and triploids, and harvesting triploids before spring/summer). Similar to results on the Pacific Coast, USA (Green et al. 2023), oyster farmers in Alabama and Mississippi are primarily limited from readily relocating their farms because of strict location regulations. The permitting process to establish an aquaculture operation in Alabama involves gaining approval from six different state and federal agencies, which evaluate farm location and operations (Alabama Seafood Marketing Commission 2025). In Mississippi, most farmers must use the Deer Island Aquaculture Park (Mississippi Department of Marine Resources 2025), unless they have waterfront property and can exercise their riparian rights (for more information, see Chapter 2). Thus, it is difficult for farmers to have more than one location where they can move their equipment during stressful environmental conditions.

Oyster farmers are also limited due to financial considerations. Most farmers in the Gulfgrow triploid oysters instead of diploid. This third set of chromosomes makes oysters sterile, which allows them to put more energy towards growth rather than reproduction (Yang 2018). These oysters grow faster and can be harvested and sold faster compared to diploid oysters, which are reproductively viable, making triploids more profitable for farmers. However, triploidy is considered a potential risk factor for mortalities (VIMS 2024), which is why VIMS (2024) recommends growing both triploid and diploid oysters. As evidenced by results from farmer surveys, this strategy is not always feasible due to financial constraints of growing diploids because of their slower growth.

Despite their inability to pursue some of the identified strategies, this research finds that most oyster farmers monitor environmental conditions on their farm. This indicates that farmers recognize the importance of knowing how their local environments change and how this could impact their oysters and therefore their businesses. This finding was consistent to surveys conducted for Australian (Bates et al. 2021) and New England oyster aquaculture (De Master et al. 2019). Further, these strategies, though untested, may help farmers prepare for and adjust to extreme environmental fluctuations as they arise. By doing so, farmers may increase the resiliency of their farms by increasing their chances of withstanding extreme environmental conditions and allowing them to persist in the future. Similarly, other studies have indicated the importance of monitoring for better natural resources industry resilience (Green et al. 2023 and Neokye et al. 2024).

One adaptation strategy discussed by the VIMS report (2024) but not included in the survey is establishing breeding programs that result in environmental stress-resistant oyster broodstock. Both De Master et al. (2019) and Green et al. (2023) identified this strategy as one that farmers in New England and Oregon (respectively) are working to implement in the future. This strategy would involve close collaboration with oyster genetic researchers, and while some projects have been implemented in the Gulf and worldwide (Johnson and Kelly 2019, Tan et al. 2020, Yang et al. 2025), it may take some time before selectively bred oyster larvae are available for commercial production (Allen et al. 2020, Jiang et al. 2023).

4.4.2 Oyster Harvesters

For wild harvesters, this study presents evidence that scientific illustrations helped groups understand potential change. In Chapter 3, harvesters were asked whether they thought environmental change was a challenge in their industry. Most respondents (n = 22/26) did not see environmental change to be a challenge to oyster harvest, yet in this study, 16 out of 22 respondents felt that the illustrated changes could influence their oyster harvest. This is potentially because scientific illustration helped harvesters visualize environmental change as it directly affects oysters.

There are a few possible explanations as to why harvesters do not perceive environmental change as a challenge. One of these is political leaning - most harvesters identified as aligning with the conservative Republican party. According to the Pew Research Center (Kennedy and Tyson 2024), Republicans typically do not view climate change as actively affecting their communities and are less likely to make sacrifices in their lives due to climate change impacts. These results provide some explanation to those found in Chapter 3, yet more research is necessary to determine why harvesters have these perceptions. Some studies (e.g., Hill et al. 2010, Bundy and Davis 2013, Deason et al. 2014) have reviewed fishermen's local ecological knowledge in other regions and indicated that the knowledge is passed down through generations. Thus, it may be difficult for harvesters to refute their internal perceptions from historical sources and engage with potential future environmental changes.

Another possible explanation is education levels among respondents. In both this study and in Chapter 3, harvester respondents indicated low levels of post-secondary education. Studies have shown a connection between higher environmental education and environmental risk awareness, perceptions, and connections (Durmus-Ozdemir and Sener 2016, Boca and

Saracli 2019, Richardson et al. 2020), so harvesters' perceptions towards environmental change may be tied to less scientific and environmental education. However, this connection needs to be studied further in this group.

Further, harvesters' potential responses to environmental change appear limited. Though traveling to harvest oysters is a common practice along the Gulf coast depending on oyster availability or price among states as oyster harvest fluctuates (Vanderkooy 2012, Lee 2023), most harvesters are unwilling or unable to travel to another state or to start or work on an oyster farm, due to cultural connection to the resource or financial limitations. It is unclear how these barriers could be circumvented; possible ideas include supporting harvesters with resources to reduce costs associated with oyster aquaculture operations or connecting harvesters with local oyster restoration efforts.

4.4.3 Future Work

This research represents an initial investigation of how oyster farmers and harvesters could respond to a changing climate. There are numerous opportunities to further this research and identify other potential strategies for each oyster-producing stakeholder group to implement, especially across the Gulf, as oyster regulations and production rates vary across states. Similar work could also be implemented along the East and West coasts of the United States to determine how responses shift with shifting demographics and environmental challenges. Gathering these kinds of data across a region could help create region-specific strategies based on local environmental conditions and the needs of oyster producing stakeholders.

Secondly, oyster harvesters and their perceptions towards environmental change need to be further studied. Wild oyster harvesters are thought to be the most vulnerable group to climate change because of their demographic statuses and resource dependence (Humphries et al. 2019).

However, results from this study and from Chapter 3 indicate levels of unconcern from harvesters about potential environmental change. It is necessary to understand why harvesters may feel this way and how these perceptions could be involved in research or management. Future studies should include interviews and focus groups to reach harvesters and gather their perspectives, which may in turn help improve relationships between harvesters and researchers and/or resource managers.

Finally, this study focused on changes in environmental variables on the regional scale, such as temperature changes over time. While each modeled variable changed over the timeframe of our climate model, they may not overtly affect oysters as severely as indicated, as oysters are used to wide fluctuations in these variables in their natural estuarine habitats. Future work should focus on modeling the combined and long-term effects of these changes, as well as severe weather events, such as hurricanes and droughts, which are more likely to cause major impacts to oysters, such as Hurricane Katrina in 2004 (Sheikh 2005). If oyster producers and resource managers know how natural disasters may shift in frequency and intensity over the coming decades, it may help them develop other mitigation strategies and policies to help oyster populations, and therefore the oyster industry, to recover swiftly after these events (Lowe et al. 2017).

4.5 Conclusions

In this study, climate scenarios using scientific illustration and simple narration helped convey the potential effects of climate modeling results to oyster-producing stakeholders in Mississippi and Alabama. Survey results indicate that oyster farmers and harvesters have limited options to prepare for or respond to these potentially changing environmental conditions. These constraints are due to financial considerations as farmers are unwilling or unable to move their farm location; farm regulations as farmers must follow strict location permitting; and cultural connections to the oyster resource, as harvesters want to continue harvesting oysters traditionally as their families did before them rather than starting oyster farms or traveling to different states. Oysters are a climate-vulnerable species and have already faced population declines and rebounds throughout the region, thus identifying other preparation or mitigation strategies in future research is crucial for these stakeholder groups to help improve their resilience and stability for the future.

Chapter 5: Evaluating the Resilience of the Alabama and Mississippi Oyster Industries: Summary and Recommendations

This research explored the Alabama and Mississippi oyster industries in terms of their resilience to hazards and climate change utilizing social science methodologies and policy analysis. Throughout all four chapters, oyster stakeholders, especially oyster farmers and harvesters, identified many challenges to producing oysters. Below, I provide a summary and key takeaways of the completed research and offer recommendations to improve industry resilience.

In Chapter 1, a review of the Alabama-Mississippi Oyster Community of Practice, participants identified challenges within the oyster community relating to communication and a need for knowledge. The communication gaps primarily focused on regulations from the Alabama Department of Public Health (ADPH). The Community of Practice helped address these concerns by hosting meetings involving representatives from the ADPH as well as other state agencies to discuss regulations. The Community of Practice also hosted meetings to discuss programs such as oyster crop insurance and how oyster farmers could monitor environmental conditions on their farms. Overall, the Community of Practice addressed some issues within the Mississippi and Alabama oyster industries, yet there are many opportunities for this group to stay active. Perhaps just as important, the Community of Practice will help to build trust while continuing to help build communication and share knowledge within the industry.

Chapter 2 provided a comprehensive overview of oyster management policies and regulations among the Gulf states. These policies were analyzed using the coastal governance theoretical framework (Dunning 2021), which considers resiliency in a social-ecological system by how the system manages its complexity and vulnerability, and how it incorporates adaptive management, participation, and integration into management decisions. This analysis identified challenges with complexity and participation in management strategies in different Gulf states, as regulatory capacity is focused on the state level with limited regional or federal oversight. This could be perceived as both positive and negative, as singular agencies limit regulatory confusion and response times (i.e., “red tape”), but a lack of larger-scale oversight could limit how states can respond to broad-scale hazards, such as hurricanes and oil spills. Further, only two states, Louisiana and Texas, have methods to incorporate stakeholders beyond public meetings, the Louisiana Oyster Task Force and the Texas Oyster Mariculture Advisory Board. Each of these challenges represents a resiliency gap within oyster production. However, each state has demonstrated policy learning and incorporates non-regulatory research in its decision making, but these changes appear to have been retroactive rather than proactive due to the Gulf region’s long history of major hazards and resource overharvest that have negatively impacted the resource overall.

Chapter 3 involved working directly with oyster stakeholders from Mississippi and Alabama to determine their perceptions about the challenges facing the industry using interview and survey techniques. Results were analyzed using the adaptive governance theoretical framework (Dietz et al. 2003) to gauge resilience and focused on identifying how the framework’s five requirements (providing information, dealing with conflict, inducing rule compliance, providing infrastructure, and being prepared for change) as well as its three strategies (analytic deliberation, nesting, and institutional variety) were implemented within the system. Many participants, especially in Alabama, found challenges with how different regulations were changed and subsequently communicated. Participants also had many challenges with local environmental conditions and how they affected oyster production yet did not always recognize climate change as a cause. Results from this work found that stakeholders perceived that increased communication and resources from state agencies could help overcome regulatory and environmental challenges. Some of these challenges could be addressed if policymakers, resource managers, oyster researchers, and oyster farmers collaborate and create effective co-management strategies as well as communication standards where possible.

Chapter 4 identified how climate change could affect the Mobile Bay and Mississippi Sound and how oyster producers could respond. In this chapter, environmental variables were predicted 30 years from present using the Community Earth System Model version 2 large ensemble. Results indicated that environmental factors crucial to oyster development and survival would change and their combined effect could negatively impact oyster production. Scientific illustration was used to depict these changes and sent with a 10-question survey to oyster farmers and harvesters in Mississippi and Alabama. Surveys included questions relating to possible mitigation strategies, environmental data access, environmental knowledge, and others to gauge how oyster producers could respond to predicted environmental changes. Overall, this study found that there are many limitations for both oyster farmers and harvesters to implement mitigation strategies, such as financial constraints and cultural connections to traditional oyster producing methods and locations. Thus, it is important for future research to focus on developing different mitigation strategies that overcome these limitations where possible in order for oyster production to continue in a changing environment.

Overall, oysters are an important economic, ecological, and cultural species to Gulf coastal communities, yet have faced decades of overexploitation compounded with natural hazards. This research indicated that Gulf states like Mississippi and Alabama have demonstrated policy learning and have some resiliency to issues like climate change. However, because this policy learning has occurred retroactively, and oyster producers are facing many challenges with environmental stressors as well as regulations, this industry is susceptible to a major hazard or a series of hazards that would further reduce oyster production in the Gulf and put many oyster-related businesses at risk.

Given the current and future environmental stressors and competing interests along the Gulf, the future viability of the oyster industry remains uncertain. Based on the work presented in this dissertation, I provide three recommendations to help improve resiliency among the Alabama and Mississippi oyster industries:

1) Stakeholder groups, especially resource managers and oyster producers, need to improve their communication about regulations and perceived regulation challenges. This work identified numerous communication issues perceived by different stakeholder groups about regulations that have been changed or regulations that come across as burdensome and may act as a barrier to oyster production. Improved communication about regulations could help improve production as well as improve response times during hazard events. Communication could be improved by hosting meetings and generating educational material that could be distributed to oyster producers, especially when new regulations are passed or when they are changed. Community groups like the Alabama-Mississippi Oyster Community of Practice discussed in Chapter 1 would also be valuable to improve communication and increase engagement provided that state resource agencies take active participation.

2) As part of the larger effort to improve communications, Mississippi and Alabama need to incorporate more stakeholder participation in their management decisions. Mississippi once hosted an oyster task force similar to that of Louisiana, but currently both states limit stakeholder

involvement to public meetings and public comment. Encouraging stakeholder involvement could inject local ecological knowledge into decision making and help shape decisions that are beneficial for both oyster producers and the resource itself. Improved cooperation and involvement will facilitate a better managed and more resilient oyster industry. Recommendations to improve participation are to establish task forces in both Mississippi and Alabama using the Louisiana Oyster Task Force as an example. If task forces are unfeasible, another recommendation would be for state agencies to arrange regular and interactive meetings with stakeholders, such as focus groups.

3) Perhaps most importantly, governing institutions should work to build trust between themselves and oyster producers. Many of the oyster producers we interviewed do not trust or have negative feelings towards oyster policymakers and/or resource managers because they do not feel that their needs are being considered, which is rooted in miscommunication and participation issues. If there is no trust between stakeholder groups, then groups cannot collaborate and work together to solve issues within the oyster industry especially if environmental conditions worsen with climate change or coastal development. Stakeholder groups across organization types need to collaborate in order to address resilience issues so that oyster production persists into the future, as discussed in Chapter 4. Collaboration across stakeholder types is necessary to create mitigation strategies suitable to different regions and regulations as well as identifying new technologies and procedures that may make production easier in changing conditions.

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Appendix 1 – Oyster Stakeholder Interview Manual

Opener Questions:

1. Which challenges facing the oyster industry personally affect you, either now or in the past?

Demographics:

1. In which year were you born? ______________________
2. Please select the race you identify as:
   a. American Indian or Alaska Native
   b. Asian or Asian-American
   c. Black or African American
   d. White - Hispanic or Latino
   e. White - Not Hispanic or Latino
   f. Other:__________________________
3. Please select your highest level of education:
   a. Some high school
   b. High school diploma/GED equivalent
   c. Vocational/trade school
   d. Some college
   e. Bachelor's degree
   f. Some graduate
   g. Graduate degree
4. Please choose your profession in the oyster industry:
   a. Wild harvester - commercial
   b. Wild harvester - recreational
   c. Aquaculture farmer
   d. Resource manager
   e. State agency specialist
   f. Non-governmental organization specialist
   g. Seafood restaurant
   h. Seafood processor
   i. Oyster researcher
   j. Other:____________________________
5. For how many generations has your family worked in the oyster industry?
   a. 1 (I am the first in my family to work with oysters)
   b. 2 (My parent(s) worked in the oyster industry before me)
   c. 3 (My grandparent(s) and parent(s) worked in the oyster industry before me)
   d. 4+
6. In which state do you work with oysters?
   a. Alabama
   b. Mississippi
   c. Other:___________________________
7. Do you work full-time or year round in the oyster industry? Also, would you if possible?

Questions on Ecosystem Services, Challenges, and Policy:

8. Please rank the importance of live oysters to the following items:

Service	High importance	Medium importance	Low importance	Unsure
Water cleaning				
Food				
Coastal protection				
Habitat for other species				
Other (write in)				

9. Interviewer shows respondent how they scored each of the above services, and focusing on the 1-2 they ranked the highest importance, asks them <u>why</u> that particular service is important to them in their line of work?

10. Do you think oysters and oyster reefs are at risk? If so, why?

11. My state should implement more educational programs about oyster ecosystem services.
    a. Strongly agree
    b. Agree
    c. Neutral
    d. Disagree
    e. Strongly disagree
    f. Write in reasoning:

12. Do you feel that some policies in your state are causing more challenges for the oyster industry than they are solving? If so, which ones?

13. Which policies relating to oyster management and/or restoration do you find to be successful? Why?

14. What do you believe your state should be doing to help the oyster industry?

15. How (if at all) do you see the impacts of climate change in the oyster industry?

a. If the respondent says there are impacts, ask them the ways they plan to absorb or adapt to the impacts they described.

16. The best available science tells us that increasing ocean acidification may impact oyster mortality.

a. Do you have any ways that you're preparing to deal with this possible impact?

b. Who may need to step up and help the oyster industry in this situation, in your opinion?

17. Do you feel that your sector of the oyster industry is in jeopardy from the following, and if so how:

a. Climate change?

b. Policy problems?

c. Environmental problems?

18. Do you feel that you have job security in the oyster industry over the next 5, 10 years?

a. Follow up: Do you have a plan for what you would do if something were to happen to the oyster industry?

Appendix 2 – Wild Oyster Harvester Survey

1. In which year were you born? ________________________________

2. Please select your highest level of education:
   - o Some high school
   - o High school diploma/GED equivalent
   - o Vocational/trade school
   - o Some college
   - o Bachelor’s degree
   - o Some graduate
   - o Graduate degree
   - o Other: ____
   - o Decline to answer

3. How many generations of your family have worked in the oyster industry?
   - o 1 (I am the first in my family to harvest oysters)
   - o 2 (My parent(s) harvested oysters before me)
   - o 3 (My grandparent(s) and parent(s) harvested oysters before me)
   - o 4+

4. Are you an Alabama resident?
   - o Yes
   - o No
     1. If No, which state are you from? ________________________

5. What do you think are the biggest challenges in the industry currently? Select all that apply.
   - o Season length
   - o Sack limit
   - o Oyster prices
   - o Number of oysters in the water
   - o Number of harvest permits
   - o Communication with/from AMRD
   - o Environmental change (such as more hurricanes, droughts, increasing water temperatures)
   - o Pollution/water closures
   - o Other: ____
   - o Unsure

6. Please rank the importance of the oyster reefs to the following items (the same level of importance can be used more than once):

Service	**High importance**	**Medium importance**	**Low importance**	**Unsure**
Water cleaning				
Habitat for other species				

Coastal protection				
Economics (food, jobs)				
Cultural				
Other (write in)				

7. Do you think oysters and oyster reefs are at risk?
    - o Yes
    - o No
    - o Unsure

i. Optional - Why?:______________________________________

8. Do you feel that the oyster industry is in trouble from how oysters are managed?
    - o Yes
    - o No
    - o Unsure

i. Optional - Why?:____

9. Do you feel that the oyster industry is in trouble from environmental issues?
    - o Yes
    - o No
    - o Unsure

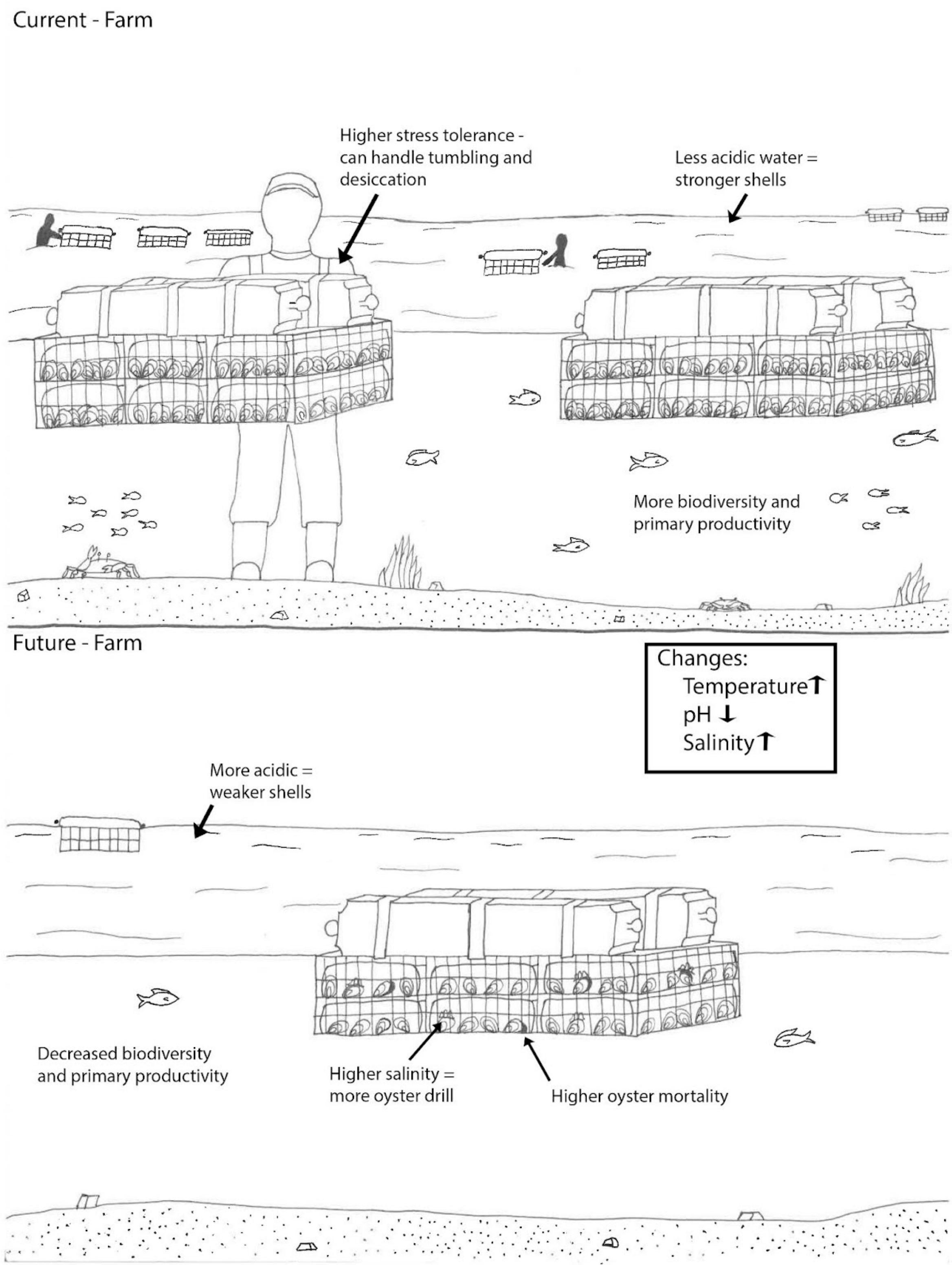
i. Optional - Why?:____

10. Do you see yourself tonging oysters over the next 5 to 10 years?

- o Yes
- o No
- o Unsure

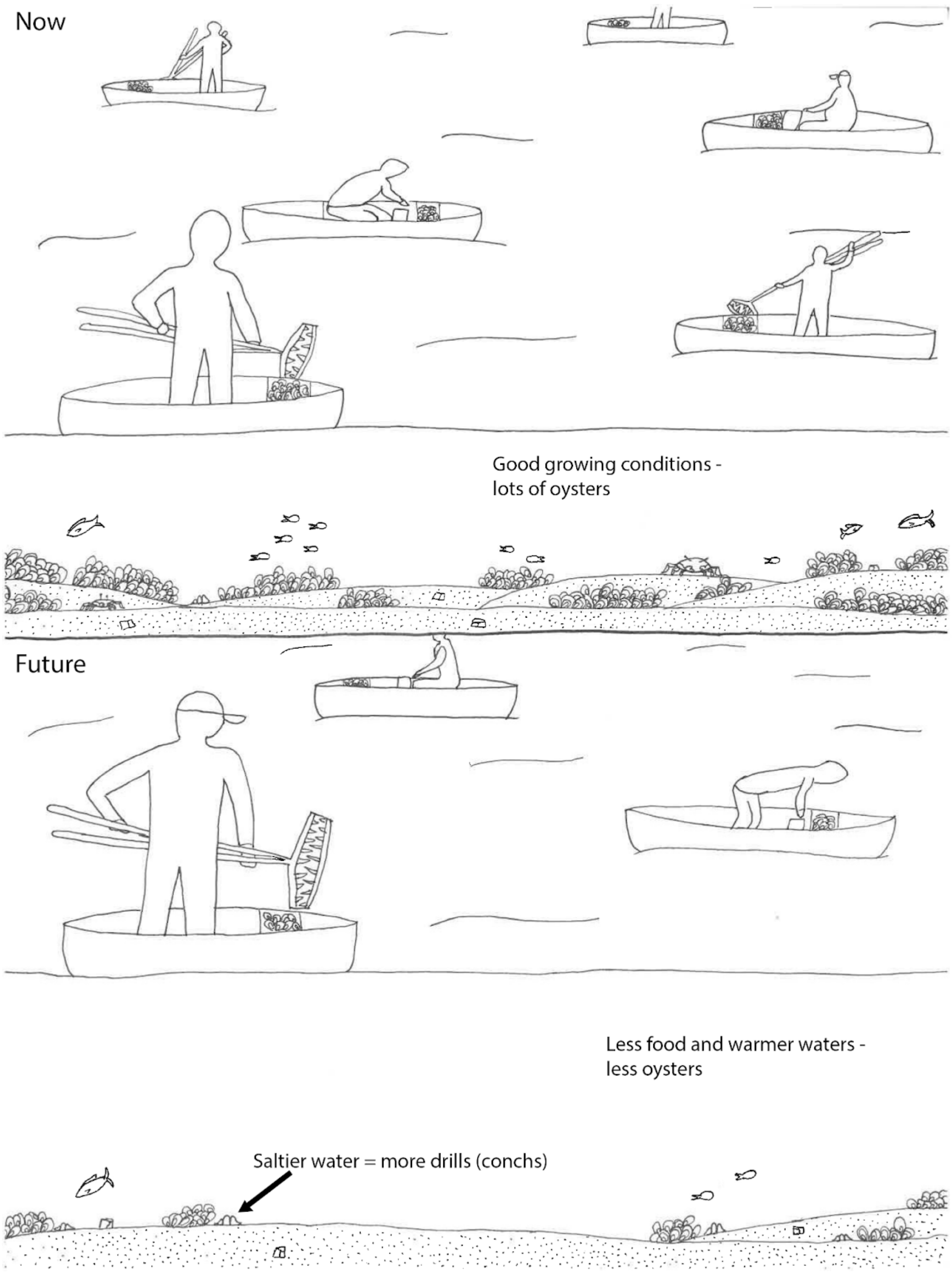
i. Optional - Why?:______________________________________

Appendix 3 – Farmer Climate Scenario & Narrative



In the next thirty years, environmental conditions will change in Mobile Bay and the Mississippi Sound. On average, we expect temperatures to increase by approximately 2.5 degrees C and salinities to increase by 0.5 ppt. Warmer, saltier waters may lead to faster oyster growth, but they may also lead to decreases in oyster ability to tolerate stress and increased presence of oyster predators like oyster drills, which will cause increased mortality. We also expect oyster food sources to decline. For example, net primary productivity, chlorophyll concentration, and zooplankton biomass will decrease. Lastly, we expect impacts on larval oysters and reproduction. Specifically, the omega aragonite saturation levels will decrease due to ocean acidification. Larval oysters use omega aragonite to generate their shells, and if there are low saturation levels, then larval oysters may experience increased mortality.

Appendix 4 – Harvester Climate Scenario & Narrative



In the next thirty years, environmental conditions will change in Mobile Bay. On average, we expect Mobile Bay to get warmer and saltier. Warmer, saltier waters can be stressful for oysters, causing oyster death. Saltier waters may also lead to more oyster drills, causing more oyster death. Oyster food sources such as algae might drop, leading to slower oyster growth. Lastly, baby oysters may have a harder time forming their shells due to these and other conditions.

Appendix 5 – Farmer Climate Scenario Survey

1. Name (optional) ___________________________________

2. How long have you owned or operated your farm?
   i) 1 year
   ii) 2 years
   iii) 3 years
   iv) 4 years
   v) 5 years
   vi) 6+ years

3. Do you think these environmental changes could negatively impact your farm operations based on your location? If so, how?

____

____

4. Of the following strategies, which are you able to implement to prevent climate-related mortality events? Select all that apply.
   i) Moving your farm to a new location
   ii) Decreasing stocking density
   iii) Minimizing handling during stressful conditions
   iv) Stocking with both diploid and triploid oysters
   v) Harvesting triploids before spring/summer
   vi) I am not able to implement any of these strategies

5. Of the available strategies, how likely are you to implement each one?

   i) Moving your farm

Very likely Likely Not likely Already implementing Cannot implement

   ii) Decreasing stocking density

Very likely Likely Not likely Already implementing Cannot implement

   iii) Minimizing handling during stressful conditions

Very likely Likely Not likely Already implementing Cannot implement

   iv) Stocking with both diploid and triploid oysters

Very likely Likely Not likely Already implementing Cannot implement

   v) Harvesting triploids before summer

Very likely Likely Not likely Already implementing Cannot implement

6. What are some reasons that prevent you from implementing some or all of these strategies? Select all that apply.
   i) Restrictive location options
   ii) Slower growth from diploids
   iii) Cost of relocating

iv) Other (please explain): ____

7. What other strategies are you aware of that could reduce the impacts of these effects on your farms? Do you implement any of these strategies already?

____

____

8. Do you keep track of environmental conditions on your farm? If so, which? Select all that apply.

i) Dissolved oxygen
ii) Water temperature
iii) Turbidity
iv) pH
v) Salinity
vi) Other (please specify) ____
vii) I do not record environmental conditions on my farm

9. Do you have access to environmental monitoring data? If so, which groups do you rely on to provide you the most up-to-date information on changing environmental conditions? Select all that apply.

i) State resource managers
ii) State regulatory agencies
iii) Non-governmental organizations
iv) Universities/oyster researchers
v) Extension
vi) Other (please specify)____
vii) I conduct my own environmental studies/review environmental literature
viii) I do not keep up with environmental monitoring data

10. Do you feel that you receive or have access to sufficient environmental condition information?

i) Yes
ii) No
    (a) If no, why? ____
iii) Unsure

11. Do you think access to environmental monitoring data could be improved? If so, how?

____

____

Appendix 6 – Harvester Climate Scenario Survey

1. Do you think these changes could hurt your oyster harvest?
   i) Yes
   ii) No
      (a) Why?
   iii) Unsure

2. Would you travel to other states to harvest oysters if you couldn't in Alabama? If so, which states would you go to? Select all that apply.
   i) Florida
   ii) Louisiana
   iii) Texas
   iv) Other:___________________________
   v) I will not travel to other states
   vi) Unsure

3. How could you prepare for these changes, if at all? Would you need any assistance from the state to do so?
____
____

4. What might you do instead if you couldn't harvest oysters?
____
____

5. Have you noticed any impact from the dredging on the oysters? If so, what?
____
____

6. Would you consider starting or working on an oyster farm?
   i) Yes
   ii) No
      (a) Why?
   iii) Unsure

7. Have you heard about ocean acidification?
   i) Yes
   ii) No

8. In what year were you born? ________________________

9. What is your highest level of education? _________________________

10. Which political party are you more likely to agree with?

Republican
Independent
Democrat
Other: ____________________________________
Prefer not to say