# Accounting for the Entire Oyster Life Cycle in Restoration Efforts:

# A Brief for Policy Makers

***The Mississippi Sound has seen a recent surge in freshwater flooding events due to multiple openings of the Bonnet Carré spillway and historic levels of coastal rainfall. Declines in oyster landings and massive die-offs have been documented in the presence of water quality stressors associated with these flooding events (i.e. low salinity/hypoxia/acidification). In 2020, a team of researchers at the University of Mississippi received funding from the Mississippi Based RESTORE Center of Excellence (MBRACE) to study the effects of stressors on early life stages of oysters. This policy brief summarizes the research team's findings and highlights the importance of these findings for oyster restoration policy in Mississippi.***

## What are the Research Takeaways?

- Water quality stressors have negative impacts on oysters in their early life stages which may limit or prevent the recovery and resilience of oyster reefs.
- Low salinity has negative effects on all early life stages, but newly settled spat were the most vulnerable.
- Salinity is an important indicator of oyster recruitment at a potential restoration site.
- Hypoxia and acidification stressors can add to the already damaging effects of low salinity and need to also be considered when accounting for the entire oyster life cycle.

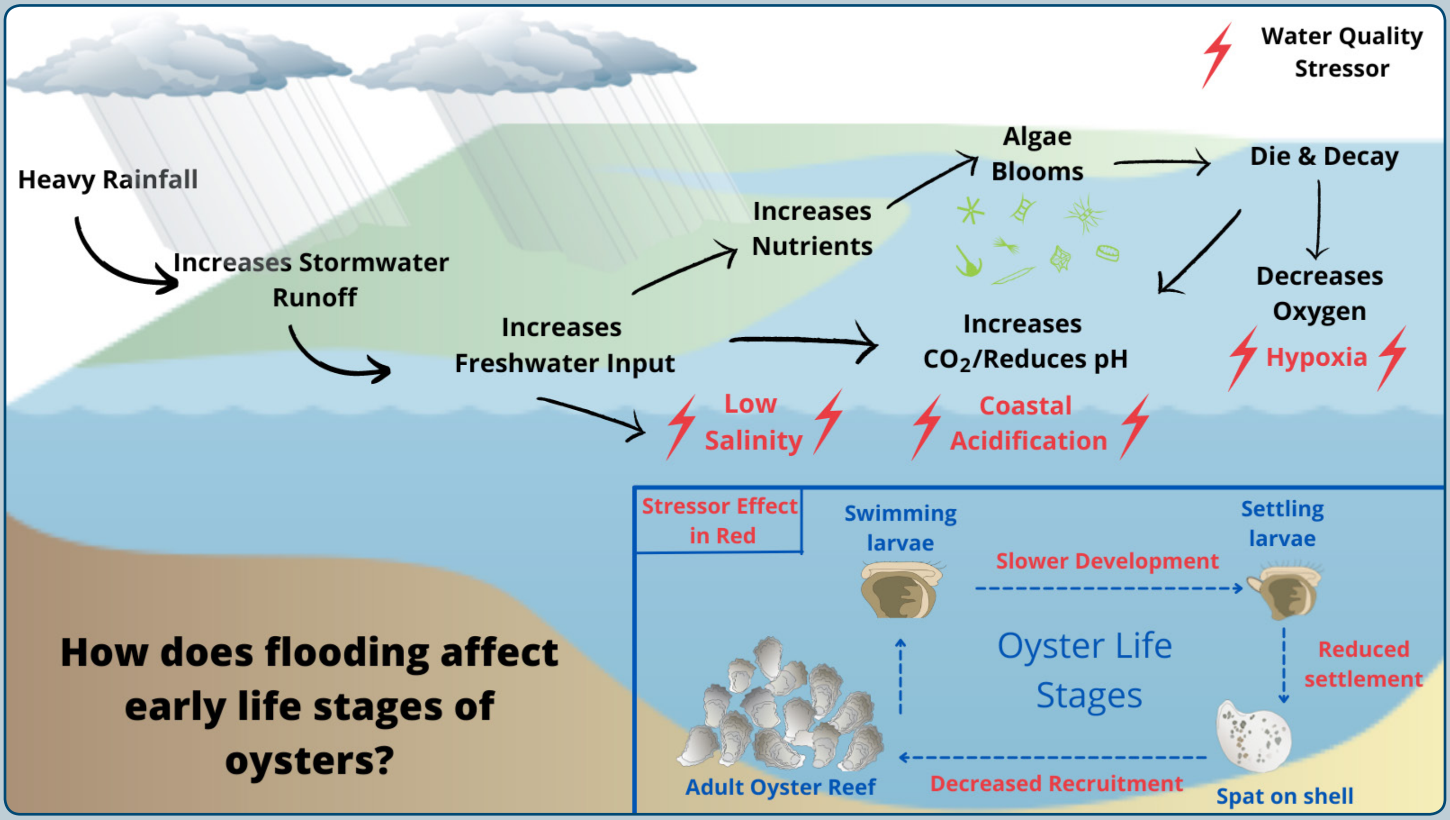



***Figure 1:*** *Impact of flood associated water quality stressors on early oyster life stages. Images from the Integration and Application Network (ian.umces.edu/media-library).*

## What has Happened to Mississippi's Oysters?

In the early 1900s, Biloxi, Mississippi was known as the "Seafood Capital of the World" due to the large amount of shrimp and oysters landed and processed in the city. Today, the Gulf of Mexico continues to support the largest wild oyster fishery in the world, but catches have declined significantly in recent years. Between 2000 and 2009, oyster harvesters in Mississippi were hauling in more than 2.5 million pounds every year. Then things took a turn for the worse. From 2010 to 2018, oyster harvests dropped to less than 500,000 pounds each year. There has been no public oyster harvest in Mississippi since the 2018 season.

*"Oyster Shells in Biloxi, 1908." Mississippi Department of Archives & History (https://da.mdah.ms.gov/series/cooper/detail/17466).*

What happened? Where did all the oysters go? Historically, Mississippi oyster landings have undergone cycles of boom and bust. Overharvesting during World War II led to a population crash that recovered under strong management in the 1960s, only to suffer again due to a string of natural disasters in the late 60s/early 70s. A similar story has unfolded in the 21st century. Oyster populations declined and then recovered (at least to some degree) following Hurricane Katrina in 2005, the *Deepwater Horizon* oil spill in 2010, and a major hypoxic (low oxygen) event in 2016.

Then came the Bonnet Carré Spillway openings in 2019. The U.S. Army Corps of Engineers opened the Spillway twice to prevent devastating flooding in New Orleans due to record rainfall in the Mississippi River Basin. During these openings, the largest volume of freshwater ever flowed through the Spillway. All that freshwater then flooded into the Mississippi Sound and had a devastating effect on its oyster reefs. Nearly 100% mortality was reported on public oyster reefs in Mississippi and, unlike in the other previous disasters, there have been no signs of recovery.

## What's Being Done to Restore Mississippi's Oyster Populations?

On February 2, 2015, Mississippi Governor Phil Bryant created the Governor's Oyster Restoration and Resiliency Council. The Council delivered their final report to the Governor in June 2015, setting an ambitious goal for "Mississippi to produce One Million sacks of oysters a year by 2025." For context, that is more than three times the number of oyster sacks landed by harvesters in 1999 when the fishery was perceived to be doing well. One sack of oysters is estimated to contain, on average, about 10 pounds of oyster meat. One million sacks of oysters would therefore be the equivalent to an annual harvest of 10 million pounds of oysters.

Any significant progress towards this goal would result in economic and environmental benefits for the state and the region. Healthy oyster reefs provide food and jobs for the people who harvest, process, and sell the oysters. Oyster reefs healthy enough to sustain that level of harvest would help keep the water in the Gulf of Mexico clean, protect the shoreline from major storm and erosion damage, and provide food and habitat for other species.

Substantial oyster reef restoration efforts are ongoing in Mississippi, with millions of dollars already spent or dedicated for future projects. The state currently has 13 active restoration projects with a combined budget of over $11 million. Restoration activities include the development of a remote setting facility, cultch deployment on historic oyster reefs, and creation of oyster spawning reefs. These projects aim to provide the two most important factors for sustainable oyster reefs: **(1)** suitable substrate for larval settlement, and **(2)** enhancement of existing reefs to promote increased larval supply.

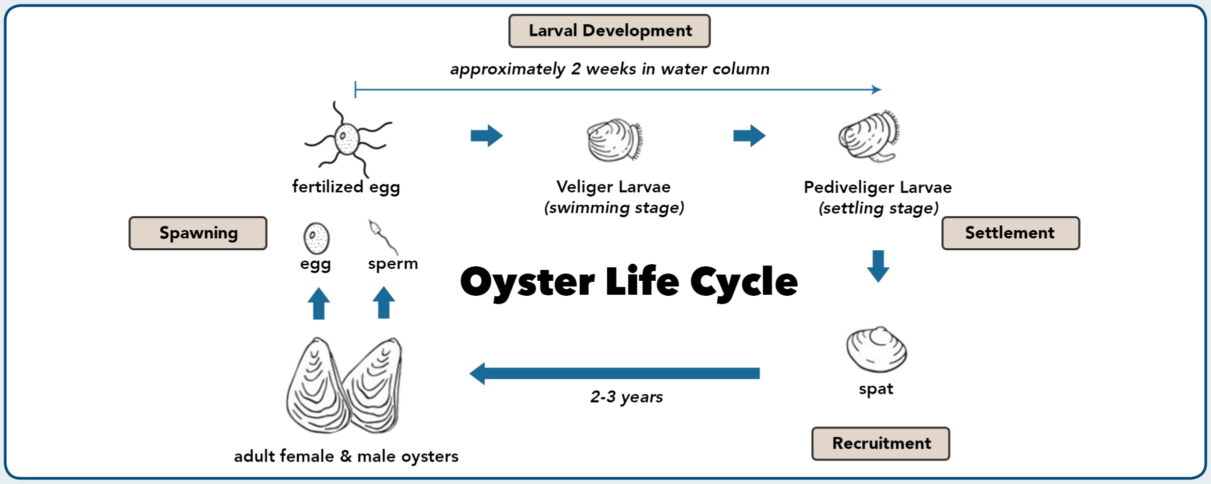



***Figure 2:*** *Oyster life cycle.*

Adult oysters cluster together in large groups to form oyster beds or reefs. In Mississippi, the eastern oyster (*Crassostrea virginica*) spawns between May and October by releasing eggs and sperm into the water column. The egg and sperm fertilize to make swimming larvae that spend 2-3 weeks dispersing before settling onto a hard surface, such as older oyster shells, rocks, or other structures. Oyster larvae that have permanently attached to a hard surface are called "spat." Whether these projects can successfully restore oyster populations in Mississippi, ultimately depends on the ability of early oyster life stages to survive and thrive in the Gulf of Mexico under current and future conditions.

## Life in the Mississippi Sound is Stressful

Estuaries, like the Mississippi Sound, are bodies of water where rivers meet the sea. The daily mixing of freshwater with saltwater in these habitats is natural but means that environmental conditions are constantly fluctuating. Oysters live in these changing environments and are usually tolerant to a range of conditions. However, when water quality is less than ideal, oysters become stressed. Younger oysters are more vulnerable to stress than adults, although the level of stress larvae and juveniles can handle is not as well known. Multiple stressors occurring at the same time can have interactive effects that make it difficult to predict the impacts on oysters.

When too much freshwater flows into an estuary at once it reduces salinity levels below the point that estuarine species can survive. Freshwater events that occur in the hotter summer months are even more stressful for oysters. Extreme floods of freshwater into the Mississippi Sound are not always the fault of Bonnet Carré Spillway openings. Heavy local rainfall can increase the amount of freshwater emptying into the Sound from major local rivers. For example, 2021 was the wettest year on record for all three of Mississippi's coastal counties and reduced salinity levels were observed at water quality monitoring stations across the Mississippi coast.

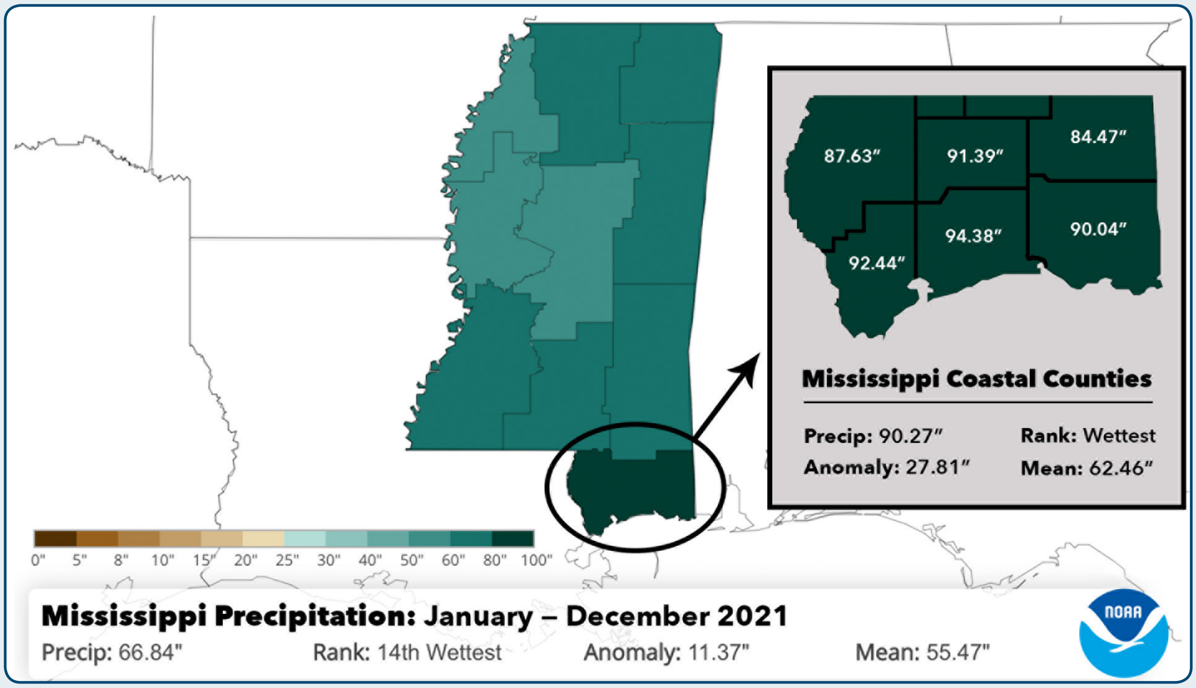



***Figure 3:*** *Average 2021 rainfall amounts for Mississippi show wettest year on record for coastal area. Screenshot and data from NOAA National Centers for Environmental information, Climate at a Glance: Divisional Mapping, https://www.ncdc.noaa.gov/cag.*

Freshwater flooding can also increase the amount of nutrients, such as nitrogen and phosphorus, in an estuary. These extra nutrients can stimulate the growth of algae and plants in the water, which is called eutrophication. Algae blooms are unsightly, smell bad, and can even release toxins that can be harmful to humans if touched or inhaled. Mississippi experienced a bloom of toxic freshwater cyanobacteria (blue-green algae) in 2019 as a result of the Bonnet Carré Spillway openings.

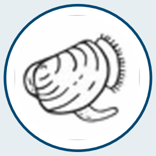
When algal blooms start to die and decompose, bacteria grow and use up the oxygen in the surrounding water, suffocating animals - like oysters - that can't move out of harm's way. Low oxygen levels in the water are referred to as hypoxia. Like other living things, bacteria release $CO_2$ when they breathe, which can lead to lower pH levels in estuaries. Additionally, freshwater flowing from rivers during flooding events is often more acidic than oceanic waters. Coastal acidification is problematic for animals that use calcium carbonate to build their shell because this material can dissolve in acidified water. More frequent and intense freshwater events are predicted as climate conditions and weather pattens continue to change in the future.

## How Do Oysters Respond to these Stressors?

The success of current and future oyster reef restoration efforts in Mississippi rely on the ability of early oyster life stages to tolerate stressors during and after flooding events (i.e., low salinity/hypoxia/acidification). MBRACE-funded laboratory research at the University of Mississippi (UM) described below is helping to understand how each early life stage responds to these stressors and which combination of stressors may cause the worst outcome.

*Veliger Larvae*

**Larval Development**: Larvae are susceptible to the water quality stressors that they encounter during their swimming stage. UM researchers found that 2-day old larvae exposed to ranges of salinity, dissolved oxygen, and pH levels show high survival and can tolerate these stressors for up to 4 days of exposure. However, in extreme conditions, such as salinity less than 6 ppt or hypoxia (very low oxygen), larvae grew more slowly. Even worse, larvae exposed to both low salinity and hypoxia at the same time did not grow at all. Slower growing larvae will remain in the water column longer, which increases their chances of being eaten by predators and leaves less energy reserves for future development.

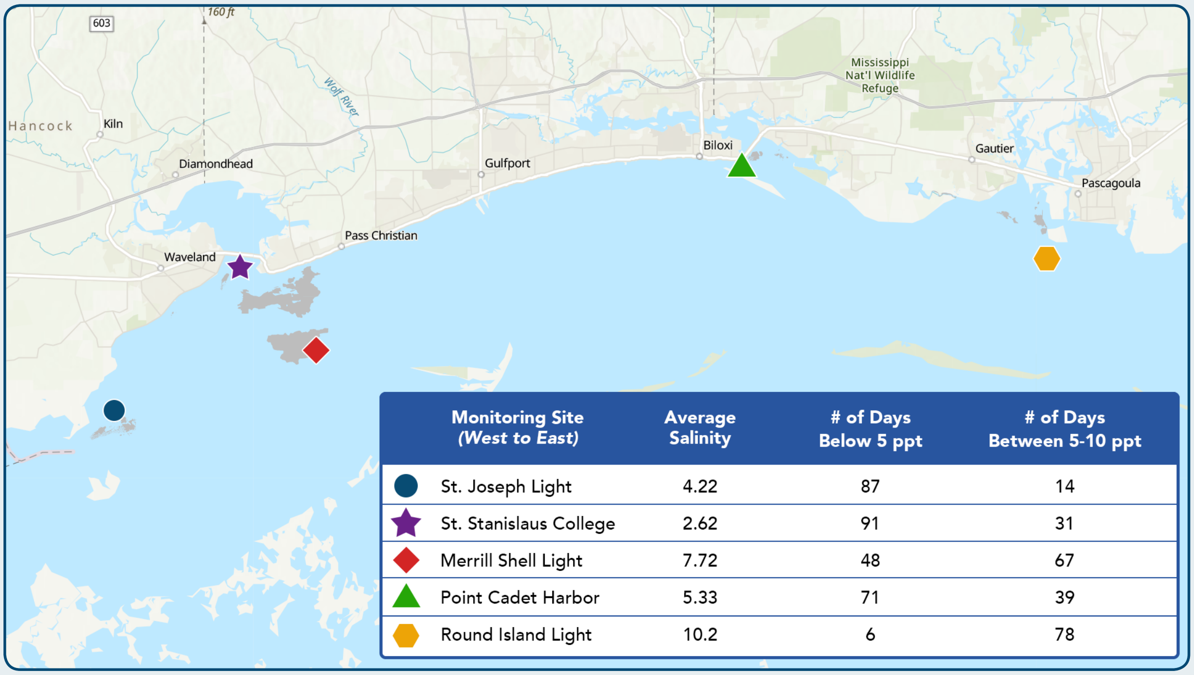


*Pediveliger Larva*

**Settlement**: By the time they're ready to settle, larvae have developed a "foot" which helps them find a solid surface for attachment. UM researchers found that fewer larvae settle on substrate when under conditions of low salinity (6 ppt), hypoxia, or acidification (pH less than 7.6). Larvae that encounter stressors soon after settling appear especially vulnerable. When researchers allowed larvae to settle under normal conditions and then exposed them to low salinity the next day, about 75% of them died. Furthermore, the survivors were much smaller than their counterparts raised in unstressed environments.

*Spat*

**Recruitment**: One-month old juvenile oysters (spat) were quite resilient to low salinity and the other stressors. However, these oysters grew more slowly when exposed to any of the stressors compared to unstressed oysters. When spat was exposed to all three stressors (salinity, hypoxia, and acidification) at the same time, they experienced negative growth - meaning they actually got smaller. Under these acidic, low salinity conditions, the oysters' shells were dissolving faster than they could produce new shell material. Smaller, slower growing oysters are more vulnerable to predators, take longer to reach harvestable size, and may be less fertile if they reach adulthood.




| Monitoring Site *(West to East)* | Average Salinity | # of Days Below 5 ppt | # of Days Between 5-10 ppt |
|---|---|---|---|
| ● St. Joseph Light | 4.22 | 87 | 14 |
| ★ St. Stanislaus College | 2.62 | 91 | 31 |
| ◆ Merrill Shell Light | 7.72 | 48 | 67 |
| ▲ Point Cadet Harbor | 5.33 | 71 | 39 |
| ⬢ Round Island Light | 10.2 | 6 | 78 |

***Figure 4:*** *Salinity conditions during peak oyster months (May – September 2021) near priority sites for oyster restoration in Mississippi. Data from available MDMR/USGS monitoring stations or MBRACE-funded water quality monitoring.*

## What Does this all mean for Policy-makers?

Restoration projects are essential to the recovery of wild oyster reefs. The success of Mississippi's oyster restoration efforts depends on three things: **(1)** a population of healthy, reproducing adults living on the restored oyster reefs; **(2)** the development of healthy larvae to settle or "recruit" to the restored reefs; and **(3)** survival of the newly attached juvenile oysters to become healthy, reproducing adults. Larval survival and recruitment are therefore critical to achieving the state's restoration goals. Hatchery larval production for remote setting and seed aquaculture are important restoration activities that may be able to boost oyster populations in years of poor recruitment due to flooding events.

Decision-makers must take into account early life stages of oysters during the planning and implementation of restoration projects. Existing decision-making tools and models limit the ability of decision-makers to do this. While several approaches to informing restoration site selection are available, they don't currently incorporate the entire oyster life cycle. Every model also has trade-offs (pros and cons) that decision-makers must keep in mind.

Habitat Suitability Index (HSI) models are widely used to determine the suitability of a particular geographic area for oyster habitat. HSIs are often based on adult tolerance ranges of environmental stressors which are different from early life stages. For example, adult oysters can tolerate salinities between 5-10 ppt and can survive below 5 ppt for extended periods of time. But, as described above, larval settlement and spat survival are unlikely to occur below 10 ppt. Larval transport models focus on the larval stage but suffer from a lack of knowledge about stressor tolerances and spawning data specific to the Mississippi Sound. There is also limited information on how larval behavior may change model predictions, especially in stressed environments.

## So, what are the Next Steps?

Support is needed for agencies and researchers to account for early oyster life stages in restoration plans and decision-support tools, such as HSI models. A number of data sharing and collection barriers must be overcome in order to develop robust tools to guide oyster restoration decisions.

- Management thresholds should be developed to guide decision-making about when and where to place oyster seed or spat-on-shell on reefs. This restoration technique has had limited success, likely due to the vulnerability of this life stage. For example, managers should wait at least one month after spat attachment before placement on reefs and ensure that the salinity in the area is at least 5 ppt. However, salinity should be above 10 ppt for optimal success.

- Environmental data collected by state agencies, such as the Mississippi Department of Marine Resources and Mississippi Department of Environmental Quality, should be made more accessible to the entire community of practice. There is a general lack of knowledge about what environmental data is collected and how to access it. Partnerships and data sharing between state agencies and researchers can facilitate the co-production of knowledge necessary to achieve restoration goals.

- The most important environmental stressor for young oysters is salinity. The U.S. Geological Survey maintains a Coastal Salinity Index that provides information on real-time salinity conditions. However, there are just five stations in Mississippi and they are not at the priority oyster reef locations. Funding is needed to purchase, install, and maintain a network of monitoring stations to provide necessary real-time data from relevant oyster reefs to inform oyster management.

*Oyster cultch deployment in Mississippi. Photo courtesy of NOAA.*

## Recommended MBRACE-Funded Research


Gledhill J, Barnett AF, Slattery M, Willett KL, Easson G, Showalter Otts S, Gochfeld DJ. 2020. Mass mortality of Eastern Oyster *Crassostrea virginica* in the western Mississippi Sound following unprecedented Mississippi River flooding in 2019. Journal of Shellfish Research 39:235-244. https://doi.org/10.2983/035.039.0205.

Morgan LM, Rakocinski CF. 2022. Predominant factors limiting recovery of the eastern oyster (*Crassostrea virginica*) in western Mississippi Sound, USA. Estuarine, Coastal and Shelf Science 264: 107652. https://doi.org/10.1016/j.ecss.2021.107652.

Pruett JL, Pandelides AF, Willett KL, Gochfeld DJ. 2021. Effects of flood-associated stressors on growth and survival of early life stage oysters (*Crassostrea virginica*). Journal of Experimental Marine Biology and Ecology 544: 151615. https://doi.org/10.1016/j.jembe.2021.151615.


## Additional Resources


La Peyre MK, Marshall DA, and Sable SE. 2021. Oyster model inventory: Identifying critical data and modeling approaches to support restoration of oyster reefs in coastal U.S. Gulf of Mexico waters: U.S. Geological Survey Open-File Report 2021–1063, 40 p. https://doi.org/10.3133/ofr20211063.

MDMR. The Governor's Oyster Council Restoration and Resiliency Final Report. 2015.

MDMR. Oyster Management and Recovery Strategic Plan. 2021. https://dmr.ms.gov/wp-content/uploads/2022/02/Oyster-Restoration-and-Recovery-Plan_01.14.2021_final.pdf.

USGS/MDMR Real-Time Hydrological Monitoring Stations. https://dmr.ms.gov/wp-content/uploads/2019/09/Interactive-USGS-Map.pdf.



MBRACE Mississippi Based RESTORE Act Center of Excellence

Sea Grant Law Center

The University of Mississippi School of Pharmacy

The University of Mississippi

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