Sediment Diversion Operations Working Group: An Overview of Food Web Dynamics in a Louisiana Estuary

Rachel Rhode, Natalie Snider, Steve Midway, Jimmy Nelson, Randy Wells, Earl Melancon, John Fleeger, David Johnson, Beth Stauffer, Kevin Ringelman, Mike Kaller, Cassie Glaspie, Jim Cowan, and Alex Kolker

Table of Contents

INTRODUCTION:

Diversion Operations Expert Working Group:

The Diversion Operations Expert Working Group (OWG) is a multi-disciplined group of experts that together by the Environmental Defense Fund (EDF), in coordination with Restore the Mississippi River Delta coalition partners, to discuss a variety of topics related to diversion operations. Topics included:

- River Hydrodynamics and Sediment Loads
- Basin Geology and Land-Building
- Water Quality
- Wetland Health
- Fish and Wildlife
- Communities, User Groups and Socio-Economic Effects
- Operation Strategies
- Governance, Legal and Stakeholder Involvement

Each meeting focused on only one topic and by doing so the group considered how various sediment diversion operations may affect that topic. The OWG used the Mid-Barataria Sediment Diversion as a case study as it is furthest along in the engineering and design process. The group developed and shared operational recommendations with the Coastal Protection and Restoration Authority (CPRA) for consideration (Peyronnin et al. 2017). Additional information on this report can be found at http://mississippiriverdelta.org/restoration-solutions/diversion-ops-report/.

Purpose:

Due to the complex nature of fish and wildlife dynamics in relation to the operational strategy of the diversion, the larger OWG group decided it would be beneficial to list various organisms, their environmental requirements, and variables of concern. This information will provide insight on species of importance and will help support future work done for the Environmental Impact Statement (EIS) and Adaptive Management Plans of future diversions and their operations. This report will highlight many, but not all, of those species or groups of organisms that are key to understanding the dynamics of very complex estuarine ecosystems. There are many extensively researched and modeled species such as white and brown shrimp, and oysters identified in this report; groups like the Sciaenids (drum and croakers) are not described in the report but are equally important. They, along with the other functional groups and species, should be considered when examining potential influences from diversions on food web dynamics. The OWG had previously discussed indicator species, therefore those species identified may not be mentioned in this report. Those species included the American alligator, blue crab, bottlenose dolphin, eastern oyster, finfish, mammals, migratory birds, rangia clams, shrimp, and waterfowl and other water birds. More information on what was discussed and

outlined on these species can be found online at
http://www.mississippiriverdelta.org/files/2016/07/MRDRC_OWG_Supplemental-2.pdf?_ga=2.152574393.1298918624.1551105554-1084457857.1483644295.

Life-history metrics can serve to bolster our understanding of how species may react to environmental and anthropogenic perturbations. Moving forward, we cannot turn to a single metric as an indicator of sustainable species populations, but rather a system that seeks to integrate life-histories, population dynamics, and environmental stochasticity.

The report is not meant to be an exhaustive list of recommendations for additional research and monitoring. It is meant to highlight some of what has been done in the world of food web dynamics in an estuarine environment and it by no means captures all the research that exists. Many of the organisms and groups highlighted in this report are meant to show potential biological indicators of a system's response to freshwater input from a diversion and its operational strategies. Additional work would need to be completed to prioritize monitoring and research projects based on management needs and available funding.

Methods:

A smaller portion of the OWG (Natalie Snider, Steve Midway, Earl Melancon, Jim Cowan, Jimmy Nelson, Alex Kolker, and Randy Wells) met to produce a list of species that act as biological indicators. They used best professional judgement to describe potential influences on various lifecycle stages that may create a disruption or shift in the food web dynamics. Additional experts (John Fleeger, David Johnson, Beth Stauffer, Kevin Ringelman, Mike Kaller, and Cassie Glaspie) were invited after an initial meeting with the smaller group to explore gaps that were identified from the first discussion. This included an in-depth evaluation on the salinity threshold for multiple species, with special interest on those without habitat suitability index (HSI) models.

Table 1. Core members and experts that participated in the biological overview discussions.

Operations Working Group 2.0			
Name	**Title**	**Expertise**	**Affiliation**
Dr James Cowan Jr.	Professor	Fisheries	Louisiana State University
Dr. John Fleeger	Professor Emeritus	Bethic Invertebrate Ecology	Louisiana State University
Dr. Cassie Glaspie	Assistant Professor	Plankton/Benthic Ecology	Louisiana State University
Dr. David Johnson	Assistant Professor	Benthic Invertebrate Ecology	Virginia Institute of Marine Science
Dr. Mike Kaller	Professor	Aquatic Entemology	Louisiana State University
Dr. Alex Kolker	Associate Professor	Sedimentology	LUMCON/Tulane University
Dr. Earl Melancon Jr.	Professor Emeritus	Estuarine Ecology/Oysters	Nicholls State University/Louisiana Sea Grant
Dr. Steve Midway	Assistant Professor	Fisheries Ecology	Louisiana State University
Dr. James Nelson	Assistant Professor	Marine Ecosystem Ecology/Food Webs	University of Louisiana at Lafayette
Dr. Kevin Ringelman	Assistant Professor	Waterfowl Ecology & Management	Louisiana State University
Natalie Snider	Director of Science Policy	Planning/Natural Resource Management	Environmental Defense Fund
Dr. Beth Stauffer	Assistant Professor	Plankton	University of Louisiana at Lafayette
Dr. Randall Wells	Senior Scientist/Director of Sarasota Dolphin Research Progra	Dolphin Biology, Behavior, Ecology, & Health	Chicago Zoological Society/Mote Marine Lab

Estuarine Food Webs:

Coastal wetlands are critical to the ecology and economic viability of coastal Louisiana because of the diverse habitats and many ecosystem services they provide. The high concentration of estuarine wetlands is the engine behind Louisiana's productive fisheries. According to NOAA, Louisiana produces around 30 percent of the total volume of fisheries in the United States and 35 to 40 percent of the country's annual shrimp and oyster harvests (NOAA Fisheries). Water temperature and salinity are two major variables that affect at least some part of the life cycle of a large number of estuarine organisms. This group includes benthic infaunal species, crustaceans, small pelagic invertebrates, jellyfish, finfish, large predatory fish, dolphins, and birds. Seasonal variability is a critical cue for many species to enter a new life stage (e.g. recruitment and migration). The operation of the diversion will change both water temperature and salinity. The timing and duration of diversion operations will be the driver of the overall food web response. As of the time of this report, an operation plan, which lays out the timing and duration of operations, has not been completed by the State of Louisiana. The expert discussions assumed a generic operational strategy to inform this report.

The food web systems found in estuarine environments are far from simple due in part to the mixing of freshwater and salinity that creates a gradient of different estuarine habitats resulting in an abundance of many kinds of primary producers and large volumes of detritus. Bacteria and microbial communities make up a portion of the lower trophic levels of an estuarine food web. The plankton group is made up of phytoplankton, which get their energy from the sun, and zooplankton. Zooplankton feed on the phytoplankton and are then eaten by larger zooplankton, benthic invertebrates like crabs, shrimp, and oysters that filter particulate matter as a food source, and fish. Larger consumers such as sharks, birds and marine mammals prey on many of the benthic invertebrates and fish, and in the case of sharks, each other. The complexity of the food web increases as different life cycle stages of many organisms alter their role and trophic position within it. Many larvae are planktonic or nektonic and become a food source for larger predators. As they develop, their diets and trophic interactions change.

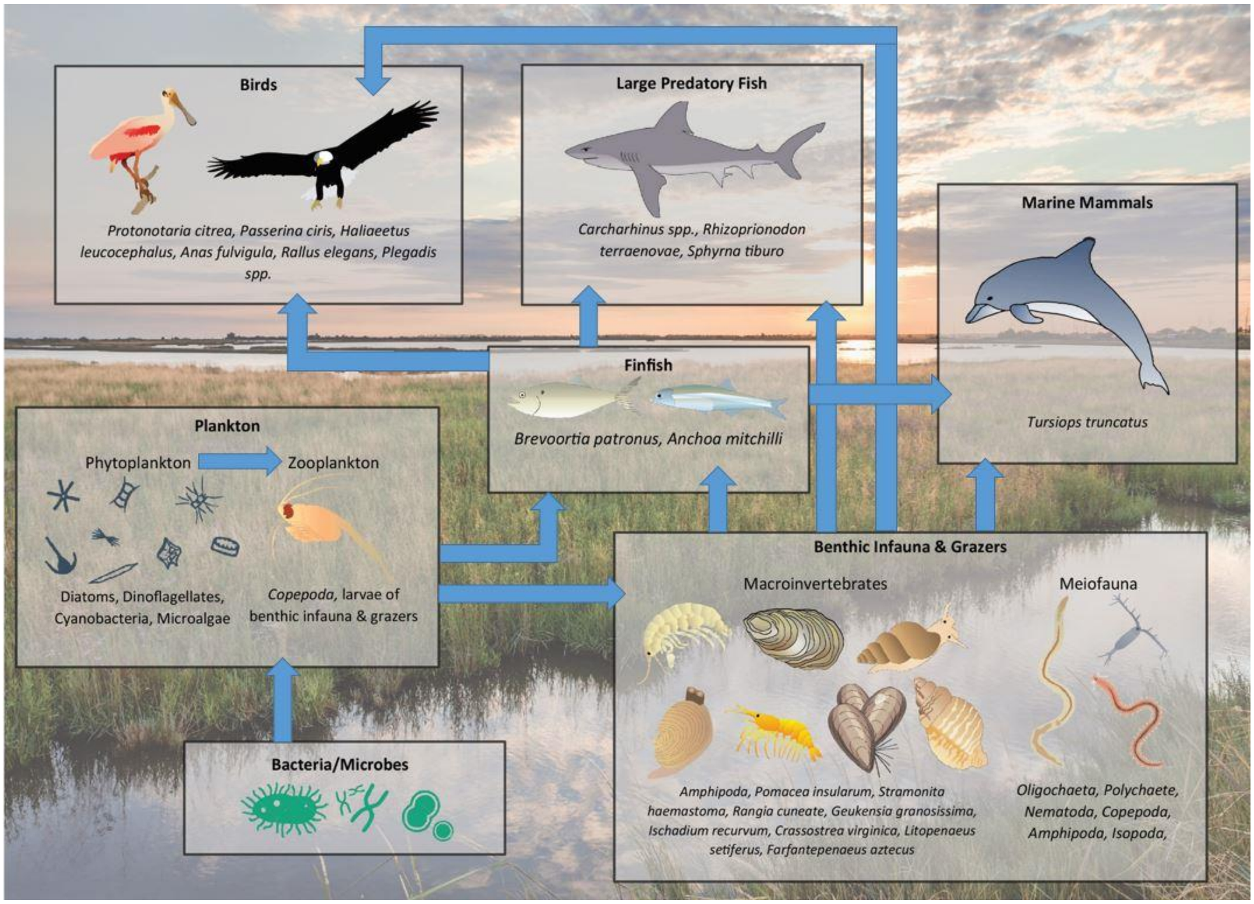

Figure 1. A generalized food web that occurs in a Louisiana estuarine system.

Each of the species in an estuary play a significant role in the overall production of the system and, when removed, could have cascading effects throughout the food web.

BACTERIA/MICROBES:

Bacteria and other microbial organisms form the basis for most, if not all, processes in the estuarine environment and are the most abundant organisms in this environment. Much of the energy and matter cycling through an estuary is done through microbial communities. Nitrogen and carbon cycling is heavily dominated by microbes and is necessary for the overall function of a food web. In all estuarine systems, the microbial components of the system establish rapidly to changing environmental conditions. Due to their high surface area to volume ratio, microorganisms make sensitive indicators of changing environmental conditions (Jackson & Vallaire 2009). The Louisiana estuarine system is nutrient and sediment limited since being cut off from the Mississippi River's influence which can affect the sediment microbial community. Enzyme activity of sediment microbial communities are an indicator of ecosystem health and can change with a change in salinity or the addition of nitrogen. Increases in salinity have shown that nutrient cycling in sediment microbial communities is reduced and bacterial diversity increases. A combination of bacterial diversity change incurred from salinities shifts and changes in enzyme activity, may suggest changes in environmental conditions (Jackson & Vallaire 2009). A study by

Bianchi et al. (2011) indicates that the influences of Mississippi River discharge from diversions can also change the signature of bacteria in Barataria Bay to more terrestrial which is defined by the chemical composition of dissolved organic material (DOM), presence of lignins and tannins, and microbial community composition. Given the importance of sediment microbial communities to biogeochemical processes in the estuarine environment, they should be heavily considered when analyzing diversions and other restoration efforts and their effects on food web dynamics.

PLANKTON & BENTHIC MICROALGAE:

Phytoplankton/Microalgae

Phytoplankton, or microalgae, are microscopic marine algae that require sunlight to survive and live in the water column. They are important players in the food web and sustain higher trophic levels in estuarine systems. They can be indicators of changes or shifts in the environment whether physical, chemical, or biological. In the Breton Sound estuary, researchers found that phytoplankton community composition to be directly influenced by salinity, temperature, and dissolved inorganic nitrogen during the operation of the Caernarvon freshwater diversion (Riekenberg et al. 2014). Shifts occurred throughout the year as well as between the upper and lower regions of the basin (Riekenberg et al. 2014).

Chlorophyll-a, a color pigment found within all phytoplankton giving them the ability to photosynthesize, is an indicator of phytoplankton biomass and water quality. Riekenberg et al. (2014) shows that with nutrient inputs (nitrate and nitrite) in the form of river discharge and seasonal variability, chlorophyll-a increases. Nutrient availability is important for phytoplankton growth and reproduction. Because of increased land use practices in the Mississippi River basin, nutrient input has increased substantially, resulting in greater phytoplankton biomass and growth. As discharge in the Mississippi River peaks in the spring, so too does the phytoplankton abundance as seen in the form of algal blooms. The Breton Sound region, which can be influenced by river discharge via the Caernarvon diversion, is one area impacted by these blooms. The chlorophyll-a and phytoplankton abundances show a trend of increasing with slow diversion input in warmer months and drops when input is high in the cooler months (Riekenberg et al. 2014). Primary production is needed to sustain upper trophic levels and nutrient input is a part of maintaining phytoplankton abundance.

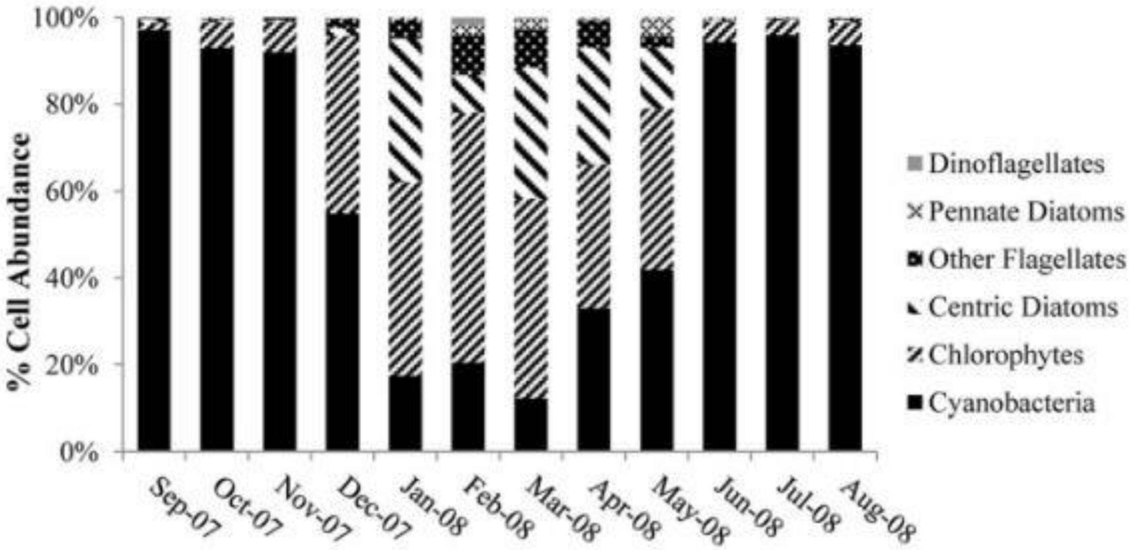

Figure 2. Percent cell abundance of different phytoplankton groups in a Breton Sound estuary from the operation of the Caernarvon diversion. The diversion has low input in the warmer months (summer to early fall) as water levels begin to drop and higher input in the cooler months (late winter to early spring) associated with snowmelt and high precipitation (Riekenberg et al. 2014).

Community shifts can alter the food web for individual organisms that carry changes throughout the entire system. Oysters, for example, are not species-selective when it comes to the type of plankton available, but they may favor larger plankton with greater nutritional value. This was identified in a study in the Chesapeake Bay in which oyster larvae exploited the presence of larger phytoplankton (Baldwin & Newell 1995). Altering the phytoplankton community can influence the nutritional quality available to the system, which can alter overall food web efficiency and lead to changes in overall production from the food web (Schmoker et al. 2016). A freshening of the system may result in a shift towards smaller organisms and larger-scale taxa and classes, such as smaller diatoms and more cyanobacteria. These changes can take place within days to weeks after a diversion opening. The mixing regime and time of year of freshening will determine how the phytoplankton community will respond.

Microphytobenthos

The microphytobenthos (MPB) is made up of microscopic eukaryotic algae and cyanobacteria like diatoms, cyanobacteria, flagellates, and green algae that live and grow in the upper few millimeters of the benthos (bottom-dwelling) where light can still reach. They typically form a biofilm on the surface of the sediment. The key distinction between phytoplankton and MPB is their position in the water column. Under calm conditions in an estuarine system, the phytoplankton in the water column can sink to the bottom, becoming a part of the MPB community as they continue to photosynthesize. The opposite can occur for MPB as sediment is stirred up during tidal currents and wind-wave interactions, thus contributing to the phytoplankton community in the water column.

Biomass of the MPB community can sometimes exceed the phytoplankton community found in the upper water column making them a larger player in the food web dynamics. MPB become important when considering the overall productivity of the system and the stability and characteristics of the benthic sediment. MPB can increase the stability of sediment and reduce resuspension by producing a sticky substance or film adhering particles together. Since MPB communities reside in the upper layers of the bottom sediment layer, they facilitate the exchange of nutrients between the sediment and the water column (MacIntyre et al. 1996).

Some studies have attempted to look at the effects salinity changes have on MPB communities. Estuarine MPB communities have been found to have the ability to withstand sudden drops in salinity (greater than or equal to 35 psu to 0 psu) (Duggan et al. 2014). However, Duggan et al. (2014) found that MPB communities can only withstand low salinities for a short period of time. Though not the exact same environment as seen in coastal Louisiana, northern Australian monsoonal tropical estuaries with wet and dry seasons that produce strong seasonal patterns of flooding, emersion and sediment deposition could provide valuable insight into possible effects on the MPB community from a diversion. Tolerance to low salinities could be beneficial during the operation of the diversion. As chlorophyll-a concentration shifted during different seasons, flooding regimes and salinities, Duggan et al. (2014) found in the same northern Australian estuary that the proportion of algal groups did not change; however, changes could have occurred at the species level, but were not captured as measuring and counting individual MPB can be difficult. As salinity is a factor for MPB, so is sediment depth. The same study determined that MPB biomass declined after sediment deposition with burial in sediment around 4 cm. Above this depth (around 1 cm) they were able to withstand sediment deposition, which is important to understand as a diversion will move and deposit sediment in the outfall area. Another important factor to consider is that MPB can vertically migrate to a degree if needed to move to more favorable conditions, though it should be noted that this migration would be on the scale of millimeters. How deep and how quickly MPB are buried in sediment can affect their ability to migrate (Duggan et al. 2014).

During flooding events and freshwater input, Duggan et al. (2014) saw negative effects on MPB biomass but, biomass increased with the return of the dry season. As floods decreased, salinity rose and drier conditions occurred after a transitional period of about three months, allowing for an increase in MPB biomass. This transition was found to be an important recovery period in the estuary for MPB not just in the near term, but also several months later. There could be a delayed positive response to sediment and nutrient input into the estuary during periods of flooding based on its duration and scale (Duggan et al. 2014). There could also be similar effects seen as freshwater and sediment is moved through a diversion. MPB play an important role as a major energy source in the food web for a number of benthic dwellers. They respond quickly to changes in a system and can provide clues into estuarine productivity.

Zooplankton

Zooplankton abundance and diversity has been found to be correlated with salinity in many estuaries among other factors, such as light and nutrient input (Helenius et al. 2017, Vieira et al. 2015). In the Gulf of Mexico, copepods are the numerically dominant group in the mesozooplankton (200um- 20mm). Communities will vary along salinity gradients (Das et al. 2012), with general trends leaning towards low diversity at around 5 psu. Freshwater zooplankton have a tendency to be fatter and higher in energy and density than saltwater species (Arts, 1999, Lee et al. 2006). Lichti et al. (2017) determined that larval fish habitat quality is an indication of the fatty acid content found in zooplankton communities, which can directly affect larval growth and survival. As species composition shifted during saltwater intrusion and freshwater input events, so too did the fatty acid composition in the zooplankton available for fish larval production. Zooplankton serve a link between the phytoplankton and upper trophic levels. Rowe (2017) claims that two primary copepod species (*Temora turbinate* and *Eucalanus pileatus*) can consume up to 50% of the phytoplankton biomass in the Mississippi River plume in a day. Main predators of zooplankton include small pelagic fishes such as anchovies and menhaden.

In addition to the abundant copepod species, the zooplankton is also made up of the larval forms of crabs, shrimp, fish, and jellyfish during parts of their life cycle. The larvae of these species are important food sources for larger predators that move into estuarine systems during spawning and recruitment of larval species. In response to past flooding events in a Louisiana estuary, zooplankton have seen short-term effects with a shift towards more freshwater-oligohaline species. As salinities returned to normal conditions, so too did the zooplankton communities (Hawes & Perry 1978).

BENTHIC INFAUNA/EPIFAUNA & GRAZERS:

Benthic infauna are organisms which live or burrow within the bottom sediments such as worms and clams. In contrast, benthic epifauna are animals, such as oysters, that attach themselves to hard surfaces like rocks or shells. Benthic grazers are those organisms that feed on the infauna and epifauna of the benthos. It could be beneficial to model benthic infauna, epifauna and grazers together. Infauna may be influenced by the diversion in the upper reaches of the estuary, but this will not matter to the food web if shrimp are not present or do not migrate to these areas during times of low salinity. Infauna may recover for the arrival of the shrimp if given enough time.

Benthic infaunal species such as clams, small crustaceans, and various types of worms will change immediately in response to diversion operations. There will likely be a shift to a community dominated by subsurface-feeding worms, which could influence the food web by making it harder for benthic predators like shrimp to find prey relative to a community with more surface-feeding worms. As salinities shift, so too will some species that have the ability to move offshore during unfavorable conditions. Benthic grazing organisms will follow the trends of the infauna and shift where productivity is high. As freshwater moves into the system, not only will an organizational shift south occur, but new communities of benthic organisms will establish that are better adapted to fresher conditions. Larger organisms like crabs and shrimp that feed on these benthic infauna species may change their diet, however, research has not been done on the relationship of infaunal invertebrate community shifts to more freshwater communities and the response of crabs and shrimp.

There is uncertainty in how the diversion's addition of nutrients into the estuarine system will alter the overall food web regardless of species. It will depend on the residence time of nutrients in the system and how long it takes for them to reach the adjacent marshes and Gulf of Mexico. Residence times of about 30 days will see most nutrient input consumed and processed within the estuary resulting in very little export to the shelf. A large diversion with high discharge rates will decrease residence times, thus, nutrients will be transported offshore rather than staying within the basin (Das et al. 2010).

There are few studies in the literature that help understand how infauna will change with diversion operations. Research in Texas estuaries on macroinfauna and meiofauna have shown diversions to be beneficial because hyper-saline conditions are common in Texas estuaries (Montagna et al. 2002). Freshwater reduces salinity stress, and infauna thrive when freshwater flow is restored. Another relevant system to consider is the wet-dry estuaries in the tropics that experience monsoonal activity. Studies of infauna suggest that during flood stages, densities, biomasses and productivity decrease dramatically but, after a transitional time, densities and biomasses recover (Duggan et al. 2014). It is possible that nutrients and conditions associated with flooding enhance the recovery of infauna when salinity increases as the monsoons end and may even super-charge productivity during the next dry phase. However, the decreases during flood times can be dramatic. Decreasing salinities, and perhaps scour or burial, during flooding conditions are considered drivers of reductions by Duggin et al. Diversions could diminish infauna during the time salinity is lowered. It might be best to minimize salinity change over time, at least in the upper reaches of the estuary, to allow more stable communities to develop there. A mature low-salinity community might be more productive than a highly disturbed community. Infauna in a higher salinity regime should be able to recover quickly from low salinity due to better dispersal abilities from high-salinity refuges offshore or closer to the coast. It should be noted that even though seasonality is reduced in the tropics, flooding in these systems occurs in the summer months which is different than the timing of proposed diversion openings in coastal Louisiana.

Meiofauna (epibenthic and infaunal worms, nematodes, juvenile polychaetes, etc.)

Meiofauna, or small benthic invertebrates, make up a large component of the estuarine food web. They serve as a critical food web link to juvenile fish and shrimp. They primarily feed on benthic microalgae, detritus, small protists, and bacteria (Rowe 2017). In Louisiana marshes, the total meiofauna densities are higher in non-vegetated mud compared to vegetated muds due to the large numbers of nematodes in non-vegetated muds. Fleeger (1985) found that the composition of meiobenthic copepods is similar in all Louisiana estuaries that were studied, but the relative abundances and dominant species varied by space and time.

Research in a northern Australian estuary, which sees wet and dry seasons in a tropical climate has shown that meiofaunal density (nematodes and copepods) decreases during consecutive flooding events (Duggan et al. 2014). A combination of immediate and continued changes in salinity and sediment movement, and subsequent burial from sedimentation from floods likely contributed to the reduced density in meiofauna. Salinity is one of the most important contributing factors known to control meiofaunal density on intertidal mudflats in estuaries of both temperate and tropical climates. Sediment deposition and scouring from flooding events can contribute to the removal of meiofauna in a region. Too much burial (>4 cm) can reduce the density of meiofauna particularly if anoxic conditions are present. However, during a transitional period of about three months between the wet and the dry seasons in which flooding was reduced and salinity increased (but still <30 psu), meiofaunal abundance remained high. Similar to the microphytobenthos, this transitional period between seasons and flooding events seems to be very important and serves as a recovery period in the estuary, where meiofaunal abundance increases even for several months after. This trend shows that a delayed positive response may occur to the sediment and nutrient input to the estuary during seasonal flooding events. The associated response could also be a result of the duration and scale of the flood (Duggan et al. 2014).

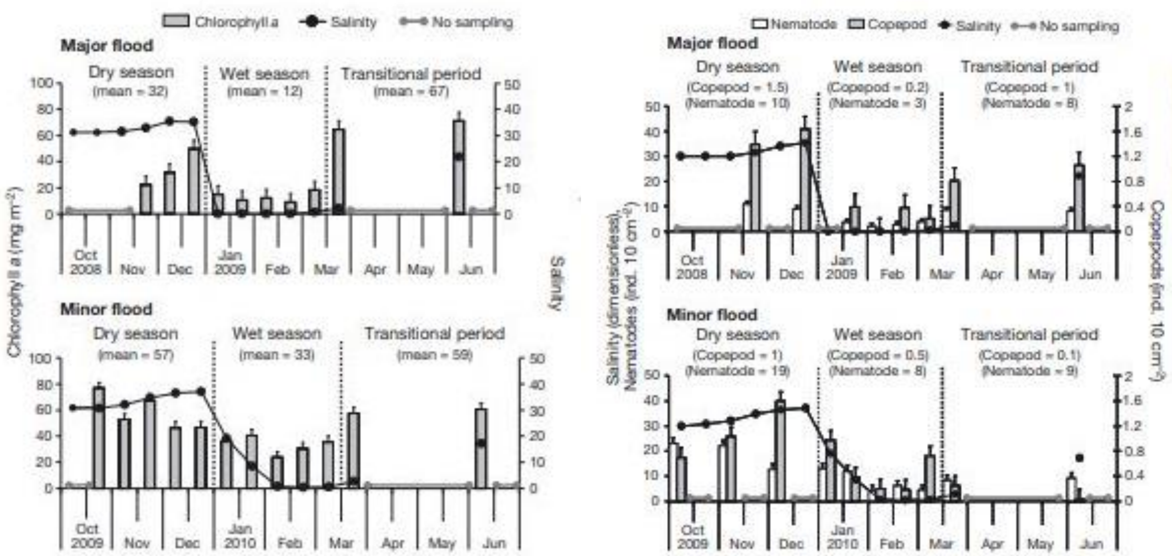

Figure 3. Density of nematodes and copepods across a number of sites in northern Australia during a major and minor flooding event. Salinity is on the y-axis (Duggan et al. 2014).

Meiofauna can be affected differently in varying climates. In colder regions, temperature is an important factor, whereas in more tropical and subtropical regions, salinity and its variations can be more important. Though Louisiana does not experience monsoons that are seen in the tropics, it does experience long summers and mild winters. Regions that are monsoonal see changes in salinity during summer months resulting in a decline in meiofaunal density. This decline is seasonal rather than permanent and densities increased during post-monsoon season similar to those seen pre-monsoon. Meiofaunal communities in tropical and subtropical regions can shift with changes in salinity and temperature. These factors can also affect the fecundity and physiological activity of these organisms. Knowing what meiofaunal groups or species are associated with specific temperature of salinity regimes can prove useful in determining whether they will be present in a given season (Ingole & Parulekar 1998).

With a diversion, the meiofauna will be in a constant state of fluctuation. As long as a tidal exchange still occurs within the system, the community will fluctuate between a high and low state of abundance. Some organisms like annelids, which have short life spans, have a more difficult time recovering if they go an entire year without reproducing. Even though annelids spawn multiple times throughout a year, missing a full reproductive cycle could affect strongly affect their population levels because they are so short lived. This could be the case for other similar organisms in the meiofauna if the diversion affects their reproductive cycles.

As the diversion comes online it is likely that meiofauna will change in response to shifts in salinity. If the quality and composition of meiofauna like copepods and nematodes change and communities begin to shift, higher trophic levels will begin to respond as well. Salt tolerant meiofauna in the system will not respond well to freshwater input and could be overtaken by species that can tolerate fresh water. However, the opposite will occur for salt intolerant species as the diversion is closed. There are few studies of the recruitment pattern of meiofauna after major events, including those that reduce their populations, to know if repopulation occurs quickly or at all. This would be important to know particularly for organisms that rely heavily on them as a food source during critical life stages. The imbalance in meiofauna populations could potentially affect predator-prey relations as well and would scale with the size and mobility of both predators and prey.

Macroinvertebrates (mussels, snails, amphipods, isopods, insects, etc.)

Macroinvertebrates are the many species of small amphipods, isopods, insects and many others that live on the surface of benthic habitats underwater and in the marsh. Their biomass and density are critical to higher trophic levels in the food web including birds and large fish. Almost all life stages of macroinvertebrates serve as an important food source for numerous species throughout the estuarine ecosystem. Each species has their own range of tolerance, making it difficult to determine how the larger composition of macroinvertebrates will shift and change based on operational strategies. Discussion indicated that there may be a little more resilience in response to the diversion coming online and it could be a longer-term change. A

OWG: Blue Crab

"Barataria Basin has a substantial population of blue crabs (*Callinectes sapidus*) which accounted for 18% of the state harvest for the period 2000-2013 (Bourgeois et al. 2014). The life stages of the blue crab have specific salinity requirements. As an adult, the females move into lower salinities to mate, usually from March to May and then migrate out to higher salinities to spawn (Guillory & Elliot 2001). The blue crab egg must hatch in high salinity waters at the mouth of the estuaries and are carried offshore. The larvae return to the nearshore to develop into a juvenile which spends most of its time in seagrass, marsh or vegetated bottoms. Spawning in Barataria Basin typically occurs off of the barrier islands and lower estuary beginning in May but usually with a major peak from August to September. As female blue crabs are pushed further offshore, possibly from diversion operations, during their spawning period, there is the possibility of increasing predator mortality due to more open water with less habitat refuge. When outside the reproductive stages, adult blue crabs (especially males) function normally in freshwater environments.
Diversion operations should be most concerned with minimizing effects to mating females in March to May and during peak spawning periods of August to September to the extent possible. Although no specific salinity range is noted in describing blue crab's needs during mating, it is generally stated that they can mate in low-salinity habitats in the Gulf of Mexico (Bourgeois et al. 2014, Guillory & Elliot 2001). Assuring some degree of brackish water during the mating period may be crucial for the species."

-Building Land in Coastal Louisiana: Expert Recommendations for Operating a Successful Sediment Diversion that Balances Ecosystem and Community Needs: Supplemental Information (Peyronnin et al. 2016)

good indicator for this group could be the Fiddler Crab (*Uca* sp.) which is easy to monitor in the ecosystem and intolerant to freshwater input. If this species' distribution or abundance patterns are undergoing changes from freshwater, it would serve as an indication of what could be occurring with marine macroinvertebrates.

Freshwater, estuarine and marine amphipod species all inhabit the estuary; they are important grazers on benthic microalgae. They are also prey to small fishes such as killifish and some birds. They lack a dispersing larval stage so they will likely be slower to recover from changes in salinity associated with diversions compared to polychaetes, which might make them a good contrasting group to research. Polychaetes and amphipods have proven to be seasonal in abundance in studies by Dr. John Fleeger of Louisiana State University focused on recovery from the Deepwater Horizon oil spill. Polychaetes recruit in the spring and amphipods become more abundant in the fall.

A study published in 2011 by Kang determined that in the Chenier Plain of coastal Louisiana the body size and taxa group of macroinvertebrates could influence their salinity tolerance. Larger invertebrates like crustaceans may be more tolerant to higher salinities than smaller groups like insects. The availability of food resources in the region during times of increased salinity could also affect the level of tolerance for invertebrates. Depending on if the eggs or larvae of the macroinvertebrates have been exposed to higher salinities, they could have greater survival rates as adults in an estuarine system (Kang 2011).

Separate from salinity, hydrologic connectivity can be important in the survival and distribution of macroinvertebrates in coastal estuarine environments. This connectivity can span from upstream freshwater systems which link up to saltier coastal bodies, forming a gradient of habitats. Such connectivity can affect the biomass, composition and density of macroinvertebrates present. When connectivity decreases, hydrologic units separate, and organisms can become stranded in a system, whereas increases in connection allow for migration and passing between bodies of water. The many gradients that form from changes in salinity within a system with hydrologic connectivity can also affect the functional feeding groups found there. These feeding groups can be indicators of the environmental conditions present in the system. Kang and King (2013) state that predators were more abundant in stable regions where hydroperiods stay fairly constant. Other functional feeding groups like piercers, scrapers, shredders and collectors are found in freshwater wetlands with submerged aquatic vegetation (SAV) to hide from predators. An understanding of the hydrologic connectivity, environmental variables and macroinvertebrate assemblages could prove useful in understanding macroinvertebrate habitat requirements and the foraging habitat for predators. In southwestern Louisiana, research showed that the highest densities and biomass was found in fresh (0.2 to 1.7 psu) permanently and temporarily connected wetlands. It's also important to note that in addition to the wetland connectivity, the duration of isolation and depth in the hydrologic connection can influence the macroinvertebrates found in the environment. Because wetlands can fluctuate and environmental conditions can vary, the system tends to be in a constant state of flux making it difficult for any one particular species or group of macroinvertebrates to dominate or adapt to all situations (Kang & King 2013).

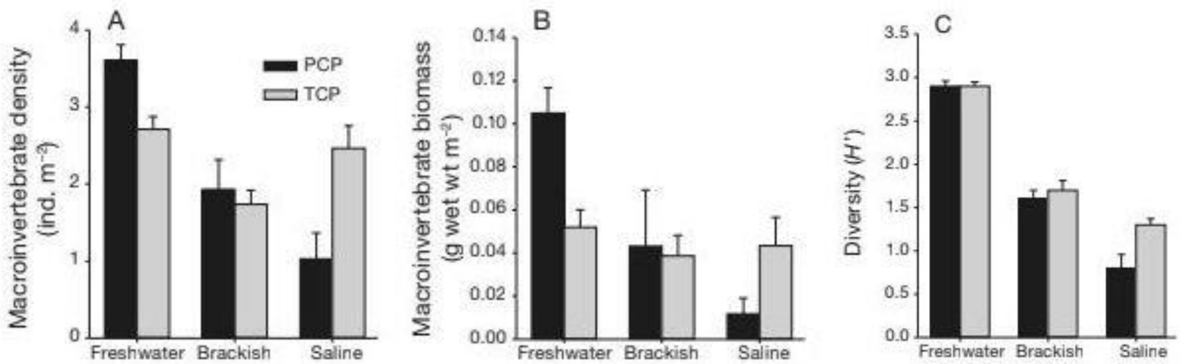

Figure 4. Graphs show the comparison of macroinvertebrate density, biomass, and diversity by pond salinity and connectivity in southwestern Louisiana. PCP = permanently connected pond, TCP = temporary connected pond (Kang & King 2013).

Apple Snail (*Pomacea insularum*)

An invasive of the Southeastern United States, *Pomacean insularum*, also known as the apple snail, has affected populations of native vegetation and other native snail species. For example, in Florida, the apple snail is known to produce significantly more eggs than the native species, leading to increased competition for food and space. Regions of low pH seems to be unfavorable for the apple snail, limiting its range in the U.S. Byers et al. (2013) found that minimum temperatures in colder months and high precipitation during the summer are favorable conditions for this species. The apple snail has been found in locations with monthly average temperatures ranging from 15 to 36 degrees Celsius, but documented reaching as low as 6 degrees Celsius. The average salinity for survival ranges from 0 to 10 psu. Researchers also discovered that more permanent and stable habitats negatively affect fecundity and survival of the apple snail. These habitats produce favorable conditions for other predators and increase diversity of species that can compete with the apple snail (Byers et al. 2013). Periodic inundation of the apple snail eggs, similar to what would occur in a natural estuarine system, has been shown to not affect the survival of eggs to hatchlings (Martin & Valentine 2014). Typically, eggs are found within 10 cm or so to the water's surface as this species is considered aquatic.

Because these snails favor fresher ecosystems, a diversion will likely cause an increase in the population; however, they may create a longer-term problem for aquatic vegetation. The apple snail feeds on aquatic plants, which can cause shifts in plant species composition, leading to an algae-dominated community (Byers et al. 2013). Metabolic activity ceases at 10 degrees Celsius or below but, apple snails can tolerate low temperatures below 10 degrees Celsius for brief periods of time if they have already been exposed to prior cold conditions, making it difficult to determine if the diversion will affect them based on temperature (Deaton et al. 2016). The diversion could keep the snails from migrating northward further into the estuary. Favorable temperatures exist at 15 degrees Celsius and above with high survivorship. Below this limit, it has been estimated the snails can survive for up to a week, depending on the size of the snail and previous exposure (Deaton et al. 2016). Periodic inundation of eggs compared to those not inundated saw similar hatch rate and survivorship. This can make predicting how the diversion will affect apple snail survival difficult (Martin & Valentine 2014). A diversion with periods of freshwater input into the system could reduce the number or kind of predators that feed on apple snails if present (Burlakova et al. 2010).

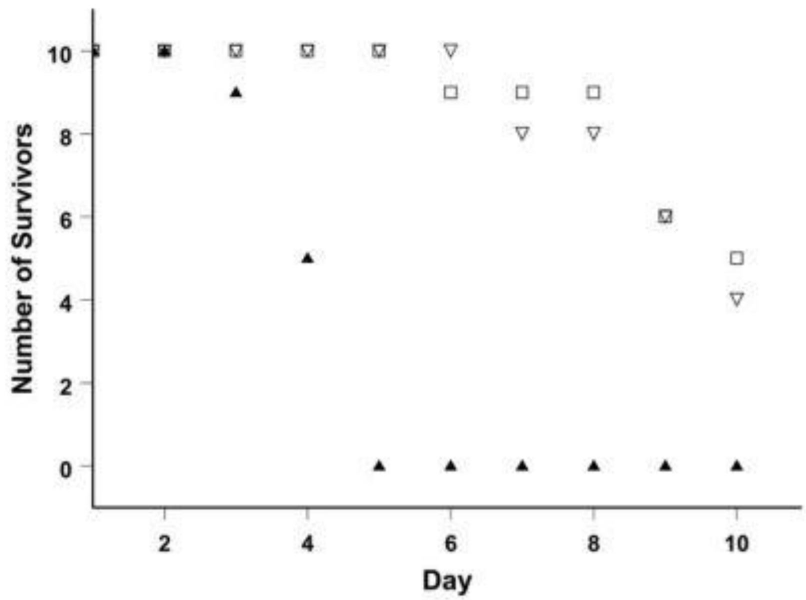

Figure 5. Depicts the number of surviving apple snails when exposed to low temperatures for 10 days. Open triangle = 10 degrees C, open squares = 5 degrees C, solid triangles = 0 degrees C (Deaton et al. 2016).

Oyster Drill (*Stramonita haemastoma*)

The small predatory sea snail known as the oyster drill, *Stramonita haemastoma*, is a major predator of oyster populations in the northern Gulf of Mexico. Oyster drills generally have a low tolerance to freshwater, are unable to handle salinities lower than 8 psu. They prefer salinities greater than 15 psu. Roller and Stickle (1989) found very high mortality at 12.5 psu and the presence of abnormal veligers (last larval stage of mollusks) at 12.5 and 15 psu, thus limiting larval tolerance to above 15 psu, with a significant influence on veligers with increasing water temperatures. A single clutch of egg capsules can number 150 or more, with each capsule containing 100 to more than 6,000 eggs; thus, a single female under optimum conditions can produce as many as 10 million eggs during a lifetime (Butler 1985). The cream-colored clutches can be found attached to pilings and mollusk shells in the spring and early summer months. Pollard (1973) documented a seasonal distribution of planktonic drill larvae in Louisiana waters from May through September with a peak in July and August.

Subtidal oyster habitat in Louisiana estuaries is intricately dependent on prevailing salinities that keep predators such as the oyster drill from devastating oyster populations (Melancon et al. 1998). The oyster drill is the single most ubiquitous predator prevalent in the higher salinity habitats of Louisiana estuaries, capable of preying on all ages and shell sizes of oysters (St. Amant 1957; Butler 1985). When a diversion is in operation and salinities are reduced, the snail may be killed or pushed farther down into the estuary. However, when the diversion is not in operation and salinity conditions become favorable, oyster drills may move back up into the estuary onto productive subtidal oyster habitat. The dilemma is that if salinities become too low, particularly during the summer and fall months, there is a chance of no gametogenesis in oysters occurring. This is regardless of if drills are reduced or eliminated due to physiological stress. If this occurs larval survival and spat set at risk. Therefore, the diversion flow's timing and estuarine salinity recovery time becomes critical habitat parameters in the case of the oyster life cycle stages when considering the predator-prey relationship of the oyster drill.

Rangia Clam (*Rangia cuneata*)

Rangia clams, *Rangia cuneata*, are a critical component of the Gulf estuarine environment (Wong et al. 2010). They fill an ecologically-important niche that no other bivalve fills. Like other species of clams, Rangia in large numbers have the ability to influence phytoplankton and particle concentrations by decreasing their clearance times, or the amount of time it takes to remove something from suspension (Wong et al. 2010). They typically spawn from March to May then again later in the summer months through November. They can live up to about eight years and need to have a good recruitment event at least every five years to maintain a stable population. Gametogenesis is triggered when the temperature is at least 15 degrees Celsius. Spawning is also induced when salinities shift (+/- 5 psu). Larvae have a specific salinity range between 2 and 10 psu that is needed in order to survive. Adults are fairly tolerant to salinity shifts, however, they tend to prefer fresher environments. Rangia are typically found in salinities less than 18 psu but prefer oligohaline conditions from 0.5 to 5 psu. Abundance can also be directly related to competition and predation. Drought conditions are considered unfavorable for Rangia as they contribute to smaller densities and size (Poirrier & Caputo 2015). Rangia serve as a food source for some birds, especially ducks and other diving birds. Though not considered a main prey for estuarine species, they could become food under less than optimal conditions for some predators. When it comes to food web dynamics, Rangia do have a positive contribution to the Gulf ecosystem as they can reduce turbidity, therefore increasing light penetration. This in turn will provide suitable vegetative habitat for other organisms. The clams themselves are suitable habitat for smaller epiphyte species. Their presence provides sediment stabilization and can help with erosion problems over time (Wong et al. 2010).

The diversion would expand the range for Rangia further down in the estuary, but they will still remain abundant. However, operating the diversion would increase turbidity and suspended sediments in the water column

OWG: Rangia Clam

"Rangia clams (*Rangia cuneata*) do especially well with a river source and are an important part of the food web. Scientists have noted an explosion of clams near the outfall of the Caernarvon Diversion and Mardi Gras Pass. This indicates that with sediment diversions, reef restoration can expand beyond oyster reefs and explore the establishment of Rangia clam reefs in the upper basin near the outfall of the diversion."

-Building Land in Coastal Louisiana: Expert Recommendations for Operating a Successful Sediment Diversion that Balances Ecosystem and Community Needs: Supplemental Information (Peyronnin et al. 2016)

which could affect filtration (Wong et al. 2010). Diversion operations should favor Rangia clams as freshwater will reduce predation on life cycle stages and recovery periods or temporary closures will induce shifts in salinity to trigger spawning and recruitment. In Galveston Bay, TX, low discharge from the nearby Trinity River in combination with drought conditions were shown to alter the environmental conditions needed for Rangia larval survival and the initiation of spawning (Windham 2015).

Ribbed Mussel (*Geukensia granosissima*)

Though much research exists on the mid-Atlantic species of ribbed mussel, less is known about its Gulf cousin. *Geukensia granosissima*, also known as the southern ribbed mussel, is a marine bivalve mollusk that can be found throughout the Caribbean, Florida Keys, and Gulf of Mexico. Seasonal fluctuation is less extreme in Louisiana and other parts of the Gulf, leading to favorable conditions for ribbed mussel spawning. Because of this, the Gulf species has an extended reproductive season. Spawning of this species is indicative of salinity shifts in midsummer when precipitation increases and again during the dry season in midwinter through spring. This suggests that salinity is important in gametogenesis of ribbed mussels. Gametogenesis typically occurs as temperatures rise above 20 degrees Celsius from February to March. Gonad maturation during early spring occurs with drops in salinity. Similar to other bivalve species, ribbed mussel males typically reach sexual maturity sooner than females in the Gulf. Ribbed mussels feed predominantly on detrital material which can be influenced by temperature shifts as decomposition occurs quicker in warmer temperatures (Honig et al 2014). According to the working group, the Gulf ribbed mussel doesn't have many known predators; however its mid-Atlantic cousin is fed upon by blue crab.

Ribbed mussels in Barataria Bay, Louisiana have been found to strongly favor *Juncus roemerianus*, also known as Black needlerush, for settlement and attachment. The Gulf species is rather tolerant to a wide range of salinities. This species has been found in salinities as low as 4 psu and as high as 15 psu. Larger densities of the ribbed mussel in Louisiana tend to be associated with the higher end of this range where *J. roemerianus* is the dominant vegetation. However, mid-salinity (average 7 psu) shows peaks in densities where predation is lower and food availability is high. The densities reported in Honig et al. (2015) were found to be significantly smaller than those of its Atlantic cousin. This is most likely due to the osmotic stress that the Gulf mussels experience in a highly variable system affected by changes in salinity. Vegetation stem density is also important for growth rates and reduced predation of the ribbed mussel. The vegetation provides anchoring substrate as well as a food source and protection from predators (Honig et al. 2015).

Diversion operations could affect the onset of gametogenesis. Honig et al. (2014) suggests that salinity reduction during spring openings and salinity increases in the late summer and fall could change the timing and output of gametogenesis in Louisiana estuaries. In addition, research suggests the Gulf species favor *J. roemerianus* as substrate, which contributes to higher growth rates and greater protection. Both the ribbed mussel and its preferred vegetation have wide salinity tolerance and therefore may not be greatly influenced by the salinity shifts that occur from diversion operations. Periodic flooding may also positively affect larval access and recruitment to preferred substrate and conspecifics (Honig et al. 2015).

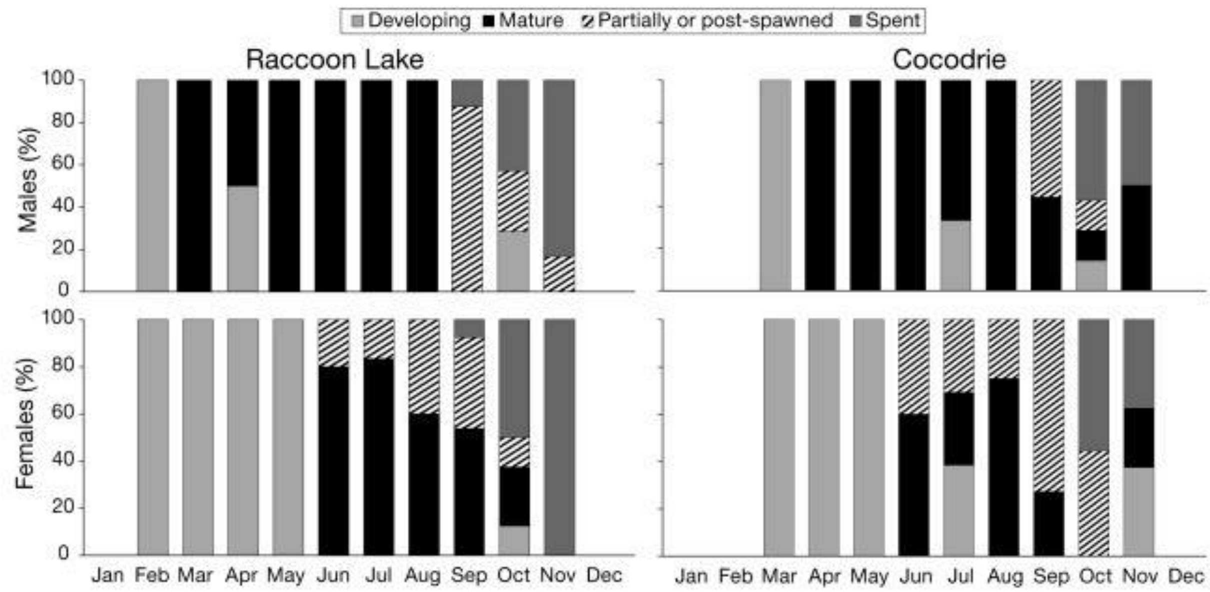

Figure 6. Depicts the seasonal gametogenic stages of the Gulf species of ribbed mussel at two locations in coastal Louisiana. January and December were not counted as the mussels were of indeterminate sex (Honig et al. 2014).

Hooked/Curved Mussel (*Ischadium recurvum)*

The hooked or curved mussel, *Ischadium recurvum*, is a species of bivalve mollusk that is prevalent in Louisiana estuaries. It is most commonly associated with oysters, using fibrous byssus threads to attach to their shells and cause them to grow in misshapen forms. The size of hooked mussels is typically influenced by the size and abundance of the surrounding oyster populations surrounding. According to Hopkins (1954), it is a major competitor with its oyster host, particularly for food and space. Hooked mussels in the Gulf are extremely abundant and euryhaline. They are mainly fed on by fish and crab, which prefer their thinner shells which make them easier to eat. The Chesapeake Bay Program designates June through October as the spawning season for hooked mussel (Chesapeake Bay Program). For a few months after spawning, the larvae swim throughout the water column until a suitable substrate for settlement is detected.

The mussel was first recorded at the mouth of the Mississippi River in the early nineteenth century and can be found from Cape Cod through the northern Gulf of Mexico and to the West Indies (Abbott 1974). Field observations in Louisiana suggest that the upper size limit is near 65-70 mm in shell length, which is similar to a maximum size reported by Abbott (1974).

Hooked mussels have an ecological role in the estuary. Gedan et al. (2014), in the Chesapeake Bay, documented that the hooked mussel often has a greater abundance and biomass than the oyster. They found that when mussels were present with oysters, the filtration capacity of the habitat increased greater than twofold. Hooked mussels were also twice as effective as oysters at filtering picoplankton (1.5–3 μm), indicating that they fill a distinct ecological niche by controlling phytoplankton in that size class.

Scientists have observed the hooked mussel abundance in relation to areas with prevailing low salinities. Brown and Richardson (1987) suggest that the hooked mussel does not survive in high salinities and is limited to low salinities in the northern Gulf of Mexico because of predation, such as by the oyster drill, *Stramonita haemastoma*. Allen (1952), working in the upper Chesapeake Bay, observed a positive correlation in the distribution of the hooked mussel with upper-estuary low salinities, as did Farias-Sanchez (1991), who observed the mussel in the Boca Del Rio-Mandiga estuarine system in Veracruz, Mexico.

Chanley (1958) investigated low salinity tolerances of the hooked mussel at specific temperatures, from Maine, Narragansett Bay and the Chesapeake Bay, and found that when transferred from 27 to 2.5 psu, between 17.6 and 24.0 degrees Celsius, the mussel could survive and feed normally. Allen (1960), working in the Chesapeake Bay, noted that oysters that were usually heavily fouled were relatively clean of the mussel after a two month winter period of low salinity. Laboratory tests by Allen indicated that, between 18-21 degrees Celsius, mussels experienced 98% mortality within 16 days at 3.6-4.5 psu; no mortality occurred by day 36 at 6-6.5 psu.

Melancon et al. (2001), in laboratory studies of three Louisiana populations of hooked mussels from three watersheds (Breton Sound, Barataria, and Terrebonne) showed that the species was highly euryhaline. The study's conclusion is based on mussels greater than 5mm in shell length. Larval and juvenile mussel salinity tolerance was beyond the scope of the study and is unknown. If mussel larvae can set and survive, resource managers and oystermen can expect to find mussels present in low-salinity waters. The hooked mussel salinity tolerance range is equal to or exceeds the lower and upper salinity range of naturally occurring subtidal oyster populations in Louisiana waters.

The Louisiana oyster industry white paper issued in May 1996 to the state legislature, and later as part of the Gulf of

OWG: Eastern Oyster

"When a reef dies, recruitment and recovery has to come from spawners elsewhere in the estuary, and there has to be a transport mechanism to allow the larvae to recruit. Understanding estuarine water circulation patterns, especially during spring and fall spawning and recruitment times, is critical to understanding how reefs can become repopulated with oysters after a freshwater die off. Intertidal oyster reefs located further south in the basni away from low salinity evets may provide spawn recruitment needed for reefs in the upper and middles basin. The southern bay distribution of intertidal reefs is also protected from predators and disease that are associated with high salinity habitats. Predation can be higher on flat, harvestable reefs as opposed to vertial, intertidal reefs…In Barataria Basin, most dips in salinity are due to precipitation as opposed to the operation of Davis Pond Freshwater Diversion (Habib et al. 2007, Swenson & Turner 1998). Occasionally, a flood with high mortality can benefit oyster populations and reef health. Oyster populations could potentially benefit from episodic flood events (approximately every 3-5 years) instead of annual flows. These occasional floods push out predators, reduce the occurrence of disease and provide shell for reefs to rebuild on (Dugas 1977). Oyster reefs can survive freshwater input in the winter months as long as the diversion operations cease by March…"

-Building Land in Coastal Louisiana: Expert Recommendations for Operating a Successful Sediment Diversion that Balances Ecosystem and Community Needs: Supplemental Information (Peyronnin et al. 2016)

Mexico Oyster Industry Initiative report to Congress, stated that the hooked mussel, *Ischadium recurvum*, is a high priority issue because of the potential for severe biofouling of commercial oyster populations. Specifically, high-priority issue #4 states, "Hooked mussel fouling on oyster growing areas has drastically increased harvesting costs by requiring laborious removal of mussels from marketable oysters or transplanting to higher salinity areas. Research on controlling or managing around hooked mussel fouling is of high priority."

The hooked mussel has been linked by oystermen to freshwater diversions used in coastal restoration efforts. Oystermen contend that an increase in freshwater into the estuaries due to the freshwater diversions have resulted in a range expansion of the mussel onto productive oyster grounds. A reduction in salinity could create favorable conditions for the mussel. Low salinity regimes may allow high hooked mussel infestation to smother an oyster crop, causing reduced growth, reduced meat yield, and increased labor and operating costs (VanderKooy 2012). Since the diversion would significantly lower salinity, there is the potential to expand the range of the mussel; infestation may be ameliorated by reintroducing estuarine predator species when salinity rebounds when the diversion is not in operation.

Eastern Oyster (*Crassostrea virginica*)

The eastern oyster, *Crassostrea virginica*, is commercially produced in northern Gulf of Mexico estuaries primarily within a salinity range of 5 to 30 psu. Optimal salinity range is 5 to 15 psu for long-term survival because of reduced predator and disease abundance (Dugas et al. 1997, Cake 1983).

Eastern oysters serve as an important food resource for many fish and invertebrates. The habitats or reefs that they create during congregation provide small habitats or refuges for many other species. According to Tunnell Jr. (2017), oyster larvae prefer salinities ranging from 10 to 27.5 psu and 5 to 40 psu for adults. Adults have higher survival rates in moderate salinities due to reduced risk from predation and disease. As water temperature increases, salinity tolerance decreases; the opposite occurs at cooler temperatures, in which they can survive for longer periods at lower salinities. If oysters are exposed for too long during freshwater events, mortality increases. Favorable temperature ranges depend on the life stage. Larvae can be found at 20 to 32.5 degrees Celsius with adults preferring 20 to 30 degrees. Oysters have the ability to tolerate low dissolved oxygen on a daily basis but prefer 20 to 100 percent saturation (Tunnell Jr. 2017).

For oysters, the presence of bacteria influence the colonization of new oysters on old shells and cultch material. Bonar et al. (1990), among others, have determined that oyster cultch is more attracted to settling when microbial films (containing bacteria, diatoms, fungi and others) are present.

The 8 psu threshold, similar to other invertebrates, is an optimal salinity for various steps of the oyster life cycle and becomes important particularly when spat larvae are prevalent in the system. If the diversion is run during the spring spat season, it is possible that populations of new oyster recruits could be lost. In this scenario, a fall spat season with 8 psu becomes important to maintain recruitment viability within the population within any given year. Fall spat should occur from

September through November, depending on the water temperature, and will be triggered as the temperature drops to around 22 to 25 degrees Celsius with salinity greater than 10 psu. If the temperature drops rapidly, a spawn will occur. La Peyre et al. (2016) found that the lowest oyster adult mortality occurred when salinity ranged from 9 to 13 psu, regardless of the temperature present at the time. When salinity dropped from 9 psu and temperature increased from 11 to 32 degrees Celsius, mortality increased. Above 13 psu, mortality rose as temperature increased. This research focused on adult oysters and did not take into consideration juvenile oysters, which have been shown to be more resilient to extreme salinity and temperature differences. The relationship between salinity and growth rates in this study of Breton Sound estuary also found that the highest growth rates of adult oysters occurred during the fall, when salinity is high, or summer, when temperatures are high (La Peyre et al. 2016).

Winter diversion operations could be favorable as many species, including oysters, can endure a dormant-like stage and survive lower salinities for several months at a time by decreasing their metabolic rate and energy outputs. Oysters may go up to three months during low salinity and low water temperature conditions and still survive. Small recovery periods or pulsing of the diversion could allow the system to revert to normal conditions. Oysters will be able to take advantage of this, even if only temporarily, to increase survival during unfavorable environmental conditions. Salinity and seasonal changes in temperature are found to control oyster growth as well as mortality. This suggests that seasonal changes to Mississippi River discharge affecting water quality in oyster grounds in coastal Louisiana can have profound effects on oyster populations. Other potential water quality effects, including increased nutrients and sediment loads, are determined to be less influential in the southern regions of Breton Sound. As the diversion is operated and salinities shift, oysters could see changes in mortality and growth rates with higher salinity conditions making oysters grow faster, however, they may also experience high mortality from disease and predation. During times of low salinity, oysters could see lower mortality rates but grow slower and have reduced gametogenesis, resulting in delayed

OWG: Shrimp

"Over the past few decades, the relative abundance of brown to white shrimp has varied based on environmental conditions and fishing pressure. Historically, white shrimp and river shrimp were dominant, not brown shrimp. Potentially, diversion operations that are based on natural flood pulses could shift the relative abundance to more white shrimp than brown shrimp. Ecologically, brown and whtie shrimp fill the same niche with similar prey and predators, and there is no known ecological detriment to having a larger population of one variation over the other. However, white shrimp populations dominating the estuary could affect the timing of predator-prey interactions since brown shrimp are fall spawners…Diversion operations could potentially increase the population of white shrimp and reduce the population of brown shrimp. Additional research is needed to confirm that there are minimal ecological consequences of this shift in dominant species and to determine the effect on the fisheries industry."

-Building Land in Coastal Louisiana: Expert Recommendations for Operating a Successful Sediment Diversion that Balances Ecosystem and Community Needs: Supplemental Information (Peyronnin et al. 2016)

spawning (La Peyre et al. 2016). The optimal locations for oyster growth could shift down the estuary with diversion operations.

Shrimp:

Both white and brown shrimp have life cycle stages that involve offshore and inshore migrations influenced by environmental conditions, habitat, and food availability. The diversion could affect their development and migratory stages depending on timing of operation, impact to salinity and water temperature during operation. Like other omnivorous crustaceans, brown and white shrimp prey on various species of meiofauna such as nematodes, polychaetes, and other small worms that live in the benthos. Meiofauna can respond rapidly to changes in salinity, resulting in a shift in the overall community. Changing the quality and composition of those meiofauna species could change the abundance, size and species of shrimp harvested. Much of what happens to shrimp prey will affect the abundance and diversity of the shrimp population. It is unknown if shrimp will be able to change their diet as shifts in prey availability occur from diversion operation.

White Shrimp (*Litopenaeus setiferus*)

White shrimp, *Litopenaeus setiferus*, are preyed upon by many finfish species and connect benthic primary production and larger fish. The larval stages of white shrimp serve as an important resource for other juvenile fish species in the Gulf of Mexico (Muncy 1984). Compared to other shrimp species, white postlarvae and juvenile shrimp can tolerate lower salinities and have a tendency to stay in estuaries for a longer period of time. They have been found to be slightly larger in size than brown shrimp. Juvenile and adult white shrimp are omnivorous and feed on detrital material, annelids, algae and plant roots (Muncy 1984). Like most shrimp, the white shrimp life cycle is dispersed among several habitats and environmental conditions. The eggs and early larval stages are found slightly offshore in nearshore coastal waters. As they develop into postlarvae they migrate into estuarine systems from May to November and can tolerate salinities between 0.4 and 37 psu. Larval forms feed on phytoplankton and zooplankton. Juveniles, however, favor less than 10 psu and migrate offshore from August to December. From spring to fall, white shrimp spawn offshore with peaks during the summer months of June and July and move back nearshore during April and May (Tunnell Jr. 2017). Spawning in the spring is triggered by sudden increases in water temperature and ends with sudden drops in temperature in the fall. Adult white shrimp have been found to be more tolerant of higher temperatures than brown shrimp, however, postlarvae in brown were more tolerant of higher temperatures than white (Muncy 1984).

A major threat to white shrimp habitat continues to be the loss of nursery grounds in the Gulf of Mexico from dredging and canal construction as well as the increase in salinities which favor brown shrimp. If salinities shift and lower with freshwater input from diversion operations during peak recruitment periods, growth rates and productivity could decline. This response will be dependent upon the magnitude, duration, and timing of operations (Rozas & Minello 2011).

Brown Shrimp (*Farfantepenaeus aztecus*)

Brown shrimp, *Farfantepenaeus aztecus*, are found to be an important source of food for many finfish; the type of predator fish varies by life cycle stage of the shrimp. Larval shrimp prey upon phytoplankton as well as zooplankton. The postlarvae stage can be found feeding on detritus and epiphytes while juveniles and adults typically eat polychaetes and amphipods. The habitat of the brown shrimp varies by life cycle stage as well. Adults and eggs spend most of their time offshore on the continental shelf and larval and juvenile stages can be found in the shallow estuaries. Larvae have a tendency to be found between 24 to 36 psu whereas the postlarvae prefer 2 to 40 psu. Narrowing even more, juveniles favor 10 to 20 psu and adults are found at 24 to 39 psu. Brown shrimp spawning is found at depths ranging from 46 to 91 m with peaks from September to May. They can spawn multiple times in a single season and typically do so at night. After spawning, postlarvae migrate into estuaries from February to April. Juveniles are found more often in open bays with adults migrating offshore to spawn from May to August (Tunnell Jr. 2017).

According to Adamack et al. (2012), not implementing the diversion could have detrimental effects to brown shrimp production due to habitat degradation over time. As marsh edge erodes, brown shrimp will have easier access to the estuary, however, as time goes on and marsh edge is further eliminated, habitat suitable for shrimp production will become unavailable. Predator populations may increase as well as the marsh edge associated with emergent vegetation disappears. Research indicated that opening the diversion early in the year for short periods of time would not greatly affect shrimp production; however, operation in April and May, regardless of duration, led to decreases in production (Adamack et al. 2012).

FINFISH:

Some fish species as juveniles prefer to utilize low salinity areas with freshwater input as refuge from predation, despite lower growth rates. It should also be noted that though biomass may not decline for some groups, their spatial distribution might change as a response to a diversion strategy (De Mutsert & Cowan 2012).

OWG: Finfish

"Some fish species have fairly stable age classes, while others are not stable, and populations tend to have strong and weak age classes due to a variety of environmental and harvest practices (May 1984). Operations for finfish productivity would best mimic the natural flood cycle. The frequency of winter flood events is anticipated to increase with climate change; however, by focusing on meta-populations over time, the seasonal timing should not be a tremendous factor. For some key species, like spotted seatrout (*Cynoscion nebulosus*), there would be very little effect as the males spend their winter in fresh water and the females tend to hunker down in deep navigation channels. In addition, in most species of finfish, juveniles are euryhaline and the salinity ranges tolerated narrow with age."

-Building Land in Coastal Louisiana: Expert Recommendations for Operating a Successful Sediment Diversion that Balances Ecosystem and Community Needs: Supplemental Information (Peyronnin et al. 2016)

Gulf Menhaden (*Brevoortia patronus*)

Some of the most commercially important species in Louisiana can be found in the finfish group. Not only are they commercially important, but they also serve as a major prey species for larger estuarine predators such as birds, jellyfish, many marine mammals and piscivorous fish. One example of this dependence is the brown pelican, which is heavily dependent on menhaden for its diet. Gulf menhaden, *Brevoortia patronus*, in particular are an important forage fish and prey. They are extremely important for their lipid and oil content commercially. Large investments are made in the menhaden industry and many aspects of the food web relies on the fish at some point in their life cycle. Gulf menhaden are predominately pelagic with long larval duration in the plankton. Spawning typically occurs in the fall through early spring from October to March (peaks in December through February) on the continental shelf in the Gulf of Mexico with larvae carried inshore into the estuaries. Eggs and larvae are found in salinities of 20.7 to 36.6 psu. Feeding larvae move further up into the estuary near river tributaries as they develop. Low salinity and nutrient-rich waters trigger metamorphosis into the juvenile stage. Early juveniles prefer low salinity (0 to 15 psu) regions nearshore in the late winter and spring with temperatures ranging from 5 to 35 degrees Celsius. Juveniles in the later stages of development move further down into the estuary into deeper waters, preferring 5 to 25 psu and temperatures from 5 to 35 degrees Celsius. As they become adults, menhaden move inshore during the spring and summer months then back to the shelf for spawning in the fall and winter. Salinity for adults ranges from 15 to 36 psu and water temperatures from 14 to 25 degrees Celsius; they are found in depths of 8 to 70 m. According to Deegan 1993, menhaden alone consume upwards of 55 percent of the productivity of an estuary, making them biomass engines. Larvae feed on phytoplankton and as they develop into the adult stages, their diet shifts to zooplankton (Chen 2017).

Gulf menhaden, according to Chen (2017), are fairly plastic to habitat changes including degradation. Even as estuarine habitat has declined over time in some northern Gulf of Mexico regions, the Gulf menhaden population has changed very little compared to other species like anchovy and croaker. Introduced freshwater into the estuarine system has increased menhaden biomass, likely due to temporary shelter from predators that prefer higher salinity conditions (Short et al. 2017).

Bay Anchovy (*Anchoa mitchilli*)

Bay anchovy, *Anchoa mitchilli*, constitutes the largest biomass of any fish in Gulf estuarine waters. They especially dominate the system during their larval stage in the summer months. Similar to menhaden, anchovy are a main source of food for many other fish including red drum, spotted seatrout, Atlantic croaker, gar, southern flounder and blue catfish. Their dominance in a system is directly influenced by the presence of zooplankton, their main food supply. Anchovy prefer to feed at night when risk of predation is lower. As menhaden move offshore to spawn, anchovy take over the estuary (Rakocinski et al. 1992). Bay anchovy are seen as an indicator of health as they are both a euryhaline and eurythermal species that can tolerate a wide range of salinities and temperatures. Most of the anchovy life cycle is spent in shallow waters with larvae favoring low saline regions and adults favoring deeper saline waters.

The bay anchovy can be found throughout most of the water column, however, they are found in greatest abundance near the first 1 to 2 m of the surface. Adults migrate to deeper waters of bays during the winter months and migrate back to shallower waters in the summer. Larvae migrate into shallower, low salinity nursery areas where zooplankton is high. As adults, they can typically be found where salinities range from 30 to 37 psu and temperatures are near 22 to 32 degrees Celsius. Just like temperature and salinity, dissolved oxygen becomes a critical factor for the survival of many organisms and is necessary for good water quality. Dissolved oxygen below 5.0 mg/L can cause stress to aquatic life and potentially deadly if low levels are sustained for even just a few hours. For bay anchovy, when dissolved oxygen levels drop below 3.5 mg/L, survival rate begins to decrease. As larvae develop into juveniles they remain in shallow estuaries where salinity is low and prey is abundant. Juveniles are found in 3 to 10 psu and 5 to 40 degrees Celsius where turbidity is higher and dissolved oxygen ranges from 1.5 to 12 mg/L. As adults, foraging occurs around 6 to 15 psu and 8 to 32 degrees Celsius. Spawning is done typically around 30 to 37 psu and less than 20 degrees Celsius from March to October in less than 20 m in depth (CPRA 2017).

Residence time will be important in terms of operational strategies chosen for the diversion and how long recovery takes between closures. Diversions may support certain life cycle stages of the bay anchovy, including the larvae and juvenile stages which favor freshwater or low salinity conditions for survival. Bay anchovy are opportunistic life history strategists that have a high enough reproductive potential to recover after a large scale perturbation such as a diversion.

LARGE PREDATORY FISH:

In the estuarine environment, large predatory fish occur in the upper trophic levels of the food web. Examples include various species of shark, which are a top apex predator in many aquatic systems. As systems change and fluctuate naturally, sharks have the ability to migrate to conditions that are favorable and support their prey. Shifts in the lower trophic systems will affect what is seen higher up in the food chain (O’Connell et al. 2007). Sharks could potentially serve as an indicator of temperature and dissolved oxygen since these environmental factors can affect their distribution and activity (Parsons & Hoffmayer 2005). Sharks are more susceptible to big changes in population because they only produce a few young each year. This makes them extremely vulnerable to large scale perturbations. If more biological information on these species, specifically longevity, age at maturity, number of reproductive events per year, and mortality rates of young can be addressed and compiled, a more robust analysis about which aspects of life history are the most important for defining chondrichthyan species that can withstand fishing pressure may be possible.

The working group established that a shark fishery is present in the Barataria estuary, however, it is seasonal and includes some large and small species such as blacktip, bonnethead, sharpnose, and finetooth. More information is needed to understand the affects that a diversion may have on this small fishery. According to the Louisiana Department of Fish and Wildlife, small coastal sharks are seasonally fished in state waters from April 1 to June 30. Shark’s position in the food web, sensitivity to dissolved oxygen and temperature, vulnerability to large scale environmental changes, and seasonal fishing pressure could make them good indicators for affects to the system from diversions.

Bull Shark (*Carcharhinus leucas*)

The bull shark, *Carcharhinus leucas*, can be found in many different bodies of water, including river mouths and lakes such as Lake Pontchartrain. The bull shark has seen a decline over the years due to habitat loss, overexploitation, and bycatch mortality. Estuaries act as highways or corridors which large predatory fish use to feed and mature. Without them, the food web dynamics would change as top-down pressures would be lessened.

Bull sharks are opportunistic feeders preying upon a variety of bony fish, smaller sharks, birds, dolphins, crustaceans and echinoderms. Few predators exist for bull sharks, but they have been known to be food for larger shark species such as tiger and great white sharks. Bull sharks have unusual reproductive habits that involve migrating to fresher estuaries and river mouths where they can bear live young. The young stay in the estuarine system as juveniles until they migrate as adults offshore. Mating typically occurs in late summer to early autumn with a yearlong gestation period in which free-swimming sharks are born. The bull shark can be found in waters up to 150 m, but are more commonly seen in waters less than 30 m. They are extremely euryhaline and can tolerate salinities up to 53 psu. This trait makes them unique among sharks and this ability provides protection for young against predators as young are born and develop in fresher systems.

Since they are so tolerant to a wide range of salinities, it is unlikely the diversion will affect them greatly. Diversion operations could alter the prey available for both juveniles and adults when they are in estuarine systems, but they are opportunistic feeders preying upon what is present. The diversion may also reduce any risk that may have existed to larger predators that cannot tolerate low salinities. Since they are one of the few top predators that can live in both fresh and saline environments, their presence affects the food web dynamics and if removed could alter lower trophic interactions.

Bonnethead Shark (*Sphyrna tiburo*)

The bonnethead shark, *Sphyrna tiburo*, is one of the most abundant species of shark found in the Atlantic and Gulf of Mexico. As there is a small fishery for this species, understanding their trophic interactions and role in the food web is important. The bonnethead, though commonly classified as a carnivore feeding on mollusks and crustaceans, does ingest a considerable amount of seagrass according to a recent study off the Gulf coast of Florida; results suggests that bonnetheads are in fact receiving some level of nutrient from ingesting seagrass (Leigh et al. 2018). This is important to note to re-evaluate how nutrient transport is occurring in the system and the critical component that seagrass beds provide to not only this species, but other levels of the food web (Leigh et al. 2018). Because bonnetheads migrate along the coast, they have the potential to distribute nutrients between multiple locations which is critical to understanding the dynamics of the greater Gulf of Mexico ecosystem.

The bonnethead shark could be adaptable to the diversion. They naturally migrate to warmer waters so the influence of the diversion may only cause them to move if the temperature isn't optimal for them. As they feed on a wide range of organisms as well as seagrass, the bonnethead may be able to adapt to the food that is available at any given time during operations, depending on how the diversion affects the seagrass beds and species available. During pupping seasons, environmental conditions may affect predation, food resources and survival; however, females have the ability to delay or shift fertilization until conditions are more favorable. This could play a larger role in their adaptation to the operation strategy of the diversion, as periods of recovery may allow conditions to become suitable for birthing. Like many large and small coastal sharks, bonnetheads play an important role in the structure and dynamics of the food web. They influence lower trophic interactions and populations as apex predators. Their presence or lack thereof in a system can affect the types of species present and their abundance. It is unlikely that salinity effects at a large-scale from the diversion will cause changes in their habitat ranges.

Blacktip Shark (*Carcharhinus limbatus*)

Like many sharks, the blacktip shark, *Carcharhinus limbatus*, exhibits late sexual maturity, low fecundity, and a highly migratory nature. This species is one of the most commercially important sharks in the northern Gulf of Mexico. Blacktips typically travel in schools and hang out near estuaries and the mouths of rivers. Preferred habitat includes shallow waters (<30 m) near continental shelves. They can tolerate low salinity for short periods of time, however it is not favorable. They are piscivorous and feed predominantly on fish such as menhaden, mullet, and herring. This species of shark is philopatric and will return to their original nursery grounds to give birth. Pups are produced every other year contributing to their high reproductive effort, but low fecundity, or ability to produce an abundance of offspring. Mating occurs from spring to early summer with an up to yearlong gestation period. Pups will stay within their nursery until fall and eventually migrate with adults to wintering locations by mid-October (Castro 1996). The Timbalier Bay region of southern Louisiana is considered an important nursery for blacktips in the summer months due to food availability and lowered predation risk (Barry 2002).

Younger blacktips in Louisiana coastal waters seek out Gulf menhaden as a primary prey item and feed mainly at night. Research suggests that blacktips are actively selecting menhaden as many other prey options are available in the area in greater abundance (Barry et al. 2008). Menhaden have been shown to have a higher caloric value than other common finfishes, which could explain the higher growth rates found in juvenile blacktips in coastal Louisiana compared to other regions in the Gulf of Mexico (Barry et al. 2008). They also have been found to feed on other small schooling fish such as herring, sardines, mullet and anchovies. They prey upon other bony fish like grouper, jacks, snook, triggerfish, and grunts. They can also feed on other sharks like dogfish, skates, and stingrays.

Diversion operation strategies should not have major effects on this species. Blacktips can move and though they don't prefer low salinities they can tolerate them for short periods of time. Recovery periods during diversion operations may provide some periods of relief needed to survive. It could be likely that a shift in prey species such as menhaden, which they rely on so greatly, will affect where this species occurs as diversions are operated. They are generalist feeders and therefore could adapt to prey species available at the time of the diversion opening assuming that the prey will be highly caloric enough to sustain them. It is unlikely that the diversion will cause large-scale salinity effects to their habitat ranges.

Atlantic Sharpnose Shark (*Rhizoprionodon terraenovae*)

The Atlantic sharpnose shark, *Rhizoprionodon terraenovae*, is an abundant species found in the Gulf in shallow coastal waters less than 10 m deep. Those found in the northern Gulf of Mexico have a seasonal migration during October and November when they can be found in deeper waters, eventually returning in April and May. Shrimp, squid, flatfish, menhaden and other small fish are the main prey for this species and they are considered generalized feeders (Barry 2002). Only other large sharks eat the sharpnose in the Gulf. Mating typically occurs between mid-May and mid-July in coastal waters where they then migrate offshore. It has been suggested by some researchers that pups are born offshore and must migrate inshore to survive (Parsons & Hoffmayer 2005). In the Mississippi Sound, the sharpnose will appear inshore when water temperatures reach 20 to 22 degrees Celsius and retreat back to deeper water in the fall when temperatures fall from 24 to 22 degrees Celsius (Parsons & Hoffmayer 2005).

The Atlantic Sharpnose fills a similar niche to that of the Blacktip Shark. Depending on how they each respond to the operation strategy of the diversion, one could overtake and dominate the niche. It is unlikely that large-scale effects will occur from the diversion. Some research hypothesizes that spikes in sharpnose growth rates in the past could be due to shark communities shifting and larger predators like blacktips witnessing a decline in abundance, resulting in an increase in prey availability for smaller sharks like the sharpnose (Carlson & Baremore 2003). As changes in food web dynamics and environmental conditions persist, some shark species including the sharpnose have been found to be smaller in size and reach sexual maturity much faster, lending to the idea that changes in biological parameters can affect growth and maturity over time (Carlson & Baremore 2003). As juveniles, the sharpnose are among the smallest

OWG: Other Large Predators: American Alligator & Mammals

"The American alligator prefers fresh marshes and will cease feeding over 10 psu. The current outfall area of the Mid-Barataria Sediment Diversion is mostly intermediate and brackish marsh, therefore the population of alligators currently in the receiving area is likely low. The elevated water levels that occur in the first 10 years may deter additional alligator nests; however, over time, the population is anticipated to grow as the diversion is operated.
Many of the mammals that live in coastal Louisiana are important to the fur-trapping industry. Many of these species, such as American mink (*Neovison vison*), river otter (*Lontra canadensis*) and nutria (*Myocastor coypus*), prefer fresh marhes. Muskrats (*Ondatra zibethicus*) prefer intermediate marshes. Diversions will increase habitat quality for most wetland mammals, including important fur-bearing species and invasive animals. Increased nutrients…will increase the density of species like nutria, muskrat and feral hogs resulting in an increase in marsh damage (Visser et al. 2006, Ialegio & Nyman 2014). Management programs…have been fairly successful and may need to be expanded to address increased herbivory. In addition, the increase in alligator population expected at diversion site will also aid in the control of the nutria population."

-Building Land in Coastal Louisiana: Expert Recommendations for Operating a Successful Sediment Diversion that Balances Ecosystem and Community Needs: Supplemental Information (Peyronnin et al. 2016)

species and benefit greatly from protected nursery grounds found in estuarine environments. The use of diversions to support and maintain the estuarine system could mean that populations of sharpnose could be sustained and restored with their operation. In the Mobile Bay region, sharpnose exhibit a level of trophic plasticity with western individuals feeding heavily on invertebrates and eastern individuals feeding on invertebrates as well as a number of teleost fish. This could be an important factor as the diversion will force many organisms to alter their diet and plasticity within the food web (Drymon et al. 2012).

Finetooth Shark (*Carcharhinus isodon*)

Another species of coastal shark found near Louisiana is *Carcharhinus isodon* or the finetooth shark. This region may serve as a nursery for pups along with providing habitat for other life cycle stages (Neer & Thompson 2004). Similar to the sharpnose, the finetooth is found in water as shallow as 10 m during summer months and no more than 20 m in the winter. Typically, they can be found in large schools of the same species. A study by Higgs (2016) at the University of Southern Mississippi found that the finetooth shark reached sexual maturity during May and June for both sexes with mating occurring shortly thereafter. Maturity was reached at a maximum of 9 years (4 years on average) for females and 6 for males. Pupping for many sharks in the Gulf occurs in late spring and early summer. Some sharks have exhibited that temperature plays an important role as the embryo develops. Warmer temperatures induce increased growth during gestation. Off the coast of South Carolina, finetooth juveniles can be found in estuarine and nearshore environments with salinities ranging from 25 to 37 psu. Neonates in this region seem to be able to tolerate slightly lower salinities to at least 18 psu up to 37 psu and are found almost exclusively in estuarine regions. Juveniles and adults migrate to warmer areas south as temperatures drop to around 20 degrees Celsius in the winter months. However, during the summer months in South Carolina, they can be found in temperatures averaging around 22 degrees Celsius. Adults tolerate a slightly smaller range of salinities than other life cycle stages at around 30 to 37 psu (Ulrich et al. 2007). It was difficult to obtain similar information for coastal Louisiana, however, each life stage for finetooths has been documented in waters off Louisiana including gravid females, suggesting that this region may serve as an important habitat nursery and pupping ground for this species (Neer & Thompson 2004). Females can reproduce annual or biennially, however, more energy is needed to reproduce annually and this can vary geographically. Gulf menhaden, among other teleosts, was found to be the main prey species for finetooth (Higgs 2016). Like most sharks, the only predators of this species is other larger sharks.

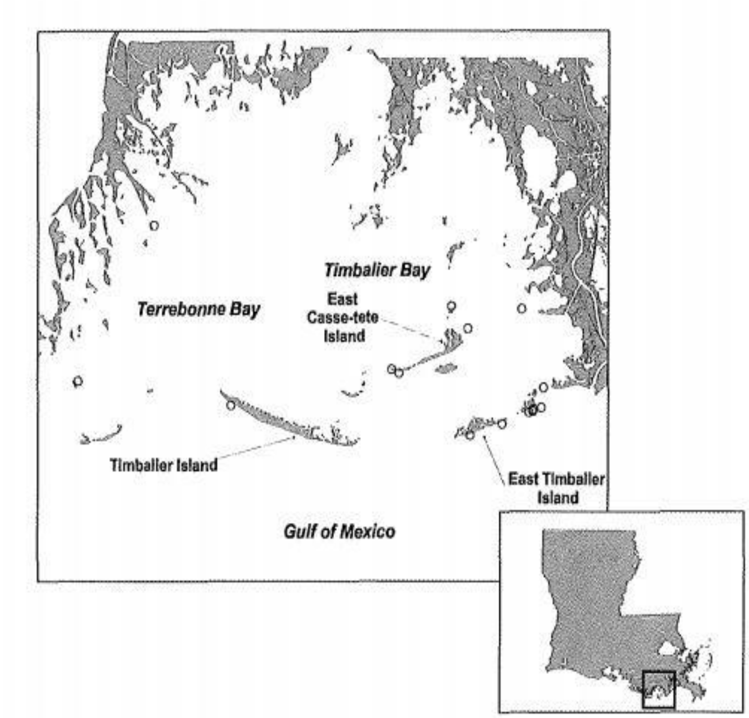

Figure 7. Locations of collected finetooth sharks in Timbalier Bay, LA (Neer & Thompson 2004).

The ability of neonates and juveniles to tolerate a slightly lower salinity than adults, could result in a diversion having positive effects on them as salinities shift and low salinity intolerant predators move out of the system. Finetooths are known to migrate and may not reside in the same waters throughout the year which would indicate that the diversion will likely not have any large-scale effects to their habitat ranges.

BIRDS:

Louisiana is host to hundreds of species of birds, including year-round residents, over-wintering species, breeding-season visitors and passage migrants. The over 300 species of birds found in coastal Louisiana at some point during the year represent a variety of functional guilds, and in many cases can be grouped based on diet, foraging style, nesting habitat needs, or all of the above. From a theoretical standpoint, increases in primary productivity at the bottom of the food web should increase avian abundance in one or more functional guilds, depending on the habitat type affected (e.g. freshwater marsh, saltwater marsh, forested wetland, etc.).

OWG: Migratory Birds

"According to the U.S. Fish and Wildlife Services' 2011 Report ("Birding in the U.S.: A Demographic and Economic Analysis: Addendum to the 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation"), bird watching is one of the most popular outdoor recreational activities in the U.S., with 47 million people over the age of 16 self-identifying as bird watchers. About 18 million people in the U.S. travel to see birds, spending about $15 billion annually on trip-related expenses. Louisiana, with its unique culture and largely underutilized wildlife viewing opportunities, could promote diversions to provide new bird watching opportunities and attract some of the ecotourism dollars…The season and size of operations will affect the species composition, diversity and abundance of birds present on any given day, which will also depend on landscape context, but providing access to the area to birders will help reveal patterns in bird responses to changing water levels and shifting habitats."

-Building Land in Coastal Louisiana: Expert Recommendations for Operating a Successful Sediment Diversion that Balances Ecosystem and Community Needs: Supplemental Information (Peyronnin et al. 2016)

Similarly, an increase in area and/or the variety of habitat types should correspond with an increase in avian community diversity.

Because of this complexity and diversity of birds, it can be difficult to predict how individual species and whole avian communities will shift in response to diversion operation strategies, however, birds are widely considered to be excellent indicators of habitat quality and diversity. As such, they are predicted to respond rapidly to changes in the landscape affected by the diversion. Potential effects to birds from the diversion include short and long-term changes to the habitat. Short-term effects include increasing water level from flooding during nesting season, extreme salinity variations affecting predictability or stability of food resources and eutrophication from depleted dissolved oxygen levels. Long-term effects will likely include changes in habitat composition, with an expansion of freshwater emergent wetlands and a southward retreat of salt marshes and open saltwater.

On the freshwater end of the estuary, the diversions would likely provide long-term benefits to conservation priority species like the Prothonotary Warbler (*Protonotaria citrea*), Painted Bunting (*Passerina ciris*), Bald Eagle (*Haliaeetus leucocephalus*), Mottled Duck (*Anas fulvigula*), King Rail (*Rallus elegans*), Glossy Ibis (*Plegadis falcinellus*) and White-faced Ibis (*Plegadis chihi*). Shallow water habitats in a productive estuary will provide important foraging habitat for a variety of additional wetland-dependent species such as egrets, herons, ibis, spoonbills, terns, kingfishers, anhinga, sandpipers, plovers, bitterns, gallinules, rails and certain wrens and sparrows. Any influx of freshwater and sediment will raise the water levels in the marsh incrementally and could make some areas wet for foraging for these species. In general, most waterfowl prefer slightly fresher conditions. In contrast, many herons and egrets, but also some waterfowl, are typically generalists in terms of salinity levels, but the abundance and diversity of small fish and invertebrates will determine or influence their presence or absence. For example, the Greater and Lesser Scaup are primarily distributed by the presence or absence of mollusks. Waterfowl are good indicators of what is occurring in the food web since they actively use the water for prey.

OWG: Waterfowl and Other Birds

"In general, waterfowl and other water birds will benefit from the low salinity, highly productive marshes created by the diversion. Diversions will lead to increased habitat quality, quantity and diversity, as well as increase submerged aquatic vegetation (SAVs) which provide a great habitat for dozens of species of waterfowl and wading birds. Because some water birds nest on or above the marsh surface or in low emergent vegetation in spring and summer, nesting seasons could be disrupted by rapid rising of water level elevations from opening of diversions. Most species would re-nest if water levels recede within the nesting season (roughly March to July), but even if not, other years without spring/summer flooding could offset losses from flooding years…Over years and decades of operation, sandbars and headlands that form would provide important nesting, foraging and loafing habitat for beach-nesting species, like terns, skimmers and shorebirds."

-Building Land in Coastal Louisiana: Expert Recommendations for Operating a Successful Sediment Diversion that Balances Ecosystem and Community Needs: Supplemental Information (Peyronnin et al. 2016)

The timing, frequency and intensity of water flows through diversion operation strategies will have varying effects on a variety of species. For example, ground-nesting birds like King Rails may lose nests in spring flooding conditions but would ultimately benefit from long-term diversion operation strategies that maximize the extent of freshwater emergent wetlands. Colonial-nesting wading birds, on the other hand, may benefit from spring flooding conditions if and when this improves foraging opportunities for fish and macroinvertebrates. A big benefit of the diversion will be its capacity to build emergent marsh and create submerged aquatic vegetation (SAV) vegetation habitat over time, which is important for foraging in waterfowl. Freshwater pulses will improve Rangia recruitment, thus providing ducks and other waterfowl that move into the system a smaller size class to forage.

MARINE MAMMALS:

Bottlenose Dolphins (*Tursiops truncatus*)

Bottlenose dolphins, *Tursiops truncatus*, are long-term, year-round residents to well-defined ranges in Barataria Bay and the vicinity (Wells et al. 2017), as is the case for bottlenose dolphins in many bays, sounds and estuaries in the Gulf of Mexico (Wells and Scott 2018). Where they have been studied in greatest detail, the ranges and social structure of resident bottlenose dolphin communities are maintained across decades and generations, with only occasional sojourns by individuals into adjacent communities (Wells 2014). In Sarasota Bay, FL, for example, as many as five concurrent generations of related dolphins occupy the community home range, including individuals up to 67 yrs. of age, with individuals observed in the bay for more than 40 years (Wells 2014). Such long-term, well-established social/population structure has been hypothesized to explain why resident communities have never been observed to shift their ranges into those of other communities, even when habitat and resources have been dramatically altered or reduced as from severe red tide harmful algal blooms, strong hurricanes, or oil spills (Wells 2014, Wells et al. 2017).

OWG: Bottlenose Dolphins

"Dolphins in Barataria Bay are not genetically homogenous (DWH MMIQT 2015) which may indicate that dolphins in this area are highly mobile and lack obvious barriers to their movement (Vollmer & Rosel 2013). While telemetry data indicates that dolphins remained in Barataria Bay over the course of the study (DWH MMIQT 2015), the lack of physical barrers, compared to those that are present in Lake Pontchartrain (Mullin et al. 2015), may allow this population to more easily move out of unfavorable reduced salinity conditions associated with diversion operations. The variation in ecological characteristics of different Bay, Sound, and Estuary (BSE) dolphin stocks in the Gulf of Mexico suggests that specific and consistent monitoring of the Barataria and Mississippi River stocks is needed to understand and better manage these populations, both with and without implementation of sediment diversion projects."

-Building Land in Coastal Louisiana: Expert Recommendations for Operating a Successful Sediment Diversion that Balances Ecosystem and Community Needs: Supplemental Information (Peyronnin et al. 2016)

Bottlenose dolphins regularly use nearly all habitats in Barataria Bay where salinity exceeds ~8 psu (Hornsby et al. 2017). They can survive brief exposures to freshwater before they develop skin lesions and ocular problems, but they are not adapted to long-term living in freshwater.

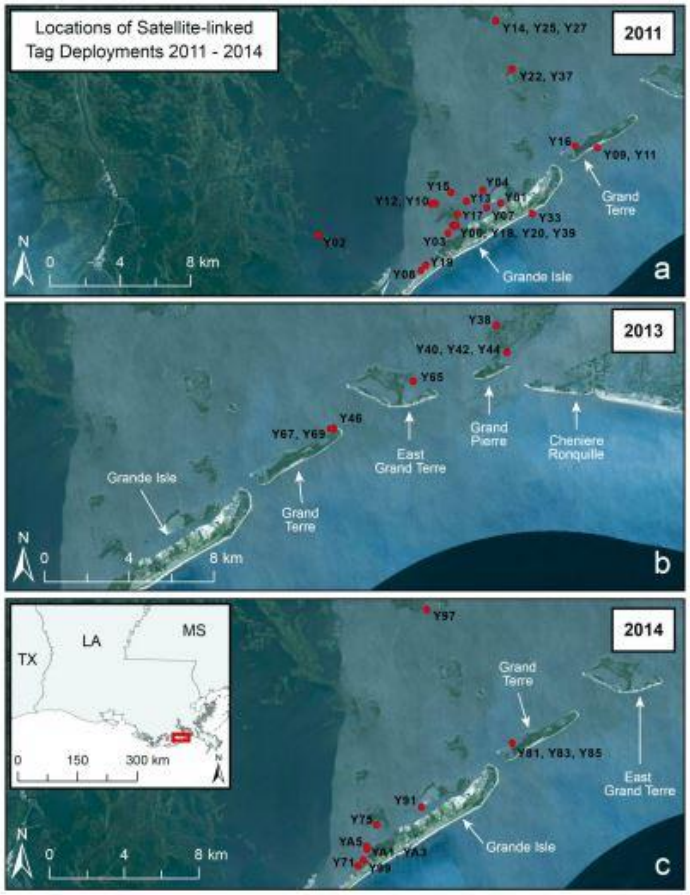

Figure 8. Deployment locations of bottlenose dolphins tagged with satellite-linked transmitters in Barataria Bay, LA from 2011 to 2014. Numbers are identification codes for each dolphin tagged at that location (Wells et al. 2017).

As top predators, bottlenose dolphins consume a variety of prey, primarily marine finfish, actively selecting soniferous, or sound-making, species (Berens McCabe et al. 2010). Adult bottlenose dolphins are estimated to consume finfish in quantities of up to 34 ± 5 kg/kg/year (Bejarano et al. 2017), with adult dolphins reaching body weights of around 200 to 300 kg.

Bottlenose dolphins produce one calf at a time after a 12.5 month gestation period, and invest three to six years in rearing each one (Wells and Scott 2018). The period immediately following birth is a crucial time for mothers and calves to bond, for the calves to begin to learn their home range and social patterns and for mothers to obtain the increased prey necessary to produce milk to support the rapidly growing calf. Lactating females require 76 percent more prey than non-lactating females (Bejarano et al. 2017). Bottlenose dolphin calving in the northern Gulf of Mexico region peaks between late winter and early spring (Urian et al. 1996).

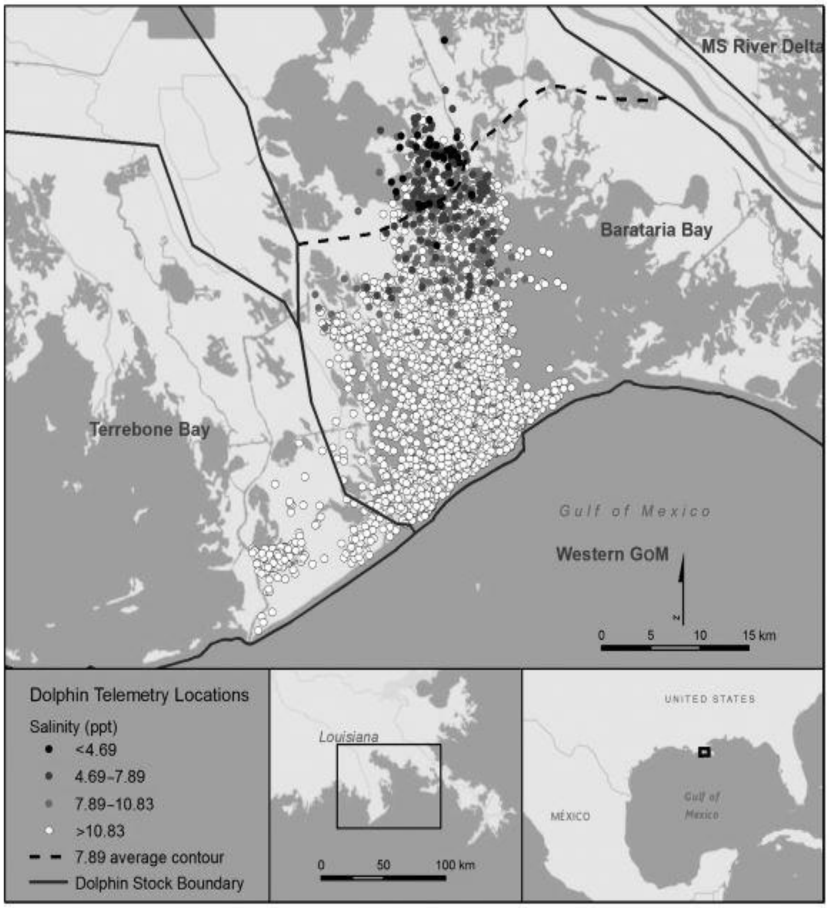

Figure 9. Map shows the Bottlenose dolphin (25 in total) telemetry locations within Barataria Bay, LA and the associated estimated salinity at each location (Hornsby et al. 2016).

It is not known how increased freshwater exposure will affect dolphins in Barataria Bay with already compromised health resulting from the 2010 *Deepwater Horizon* oil spill (DeGuise et al. 2017, Schwacke et al. 2014, 2017, Smith et al. 2017). Freshwater diversions occurring during the crucial perinatal period of March and April, and perhaps beyond, could have adverse consequences for calf survival, which is already below sustainable levels as a result of the oil spill (Lane et al. 2015, Schwacke et al. 2017). With the diversion of freshwater into Barataria Bay, it is unknown whether these dolphins will be able to shift their diets to freshwater prey fish and what effects this might have on their health and physiology. If surrounding wetlands continue to be starved of the sediments that could sustain that habitat, any portions of the dolphins' prey base reliant on these wetlands are likely to decline (Barros & Odell 1990). Dolphins that reside in coastal Louisiana routinely encounter briefly fluctuating salinity conditions, but long-term survival in Barataria Bay in the face of extended exposure to extreme low salinities is questionable.

CONCLUSION:

Food web dynamics can be influenced by the pulse of salinity in conjunction with temperature, along with the input of nutrients. Nutrient availability, in addition to the other factors, are important for the primary production that serves as a basis for the food web and in turn translates through trophic pathways into more fish for fishers (Nixon and Buckley 2002). Temperature acts as a trigger for metabolic activity and salinity is important for certain reproductive stages in many species. Apart from salinity and temperature, a combination of other environmental factors can also contribute and influence species survival. Louisiana estuaries, regardless of species, have triggers or points in which activity increases. This is typically seen around 20 degrees Celsius. Osmotic issues begin to occur at around 22 to 23 degrees Celsius and rising temperatures are too hot for many organisms.

The operation strategy of the diversion will likely influence the immediate and surrounding system and the habitats it contains. Many of the environmental conditions that some species rely on to support life cycle stages will be altered. It is important that the diversion operations plan consider critical periods of recruitment and survival. Much can be learned from the data mining that occurred after the Deepwater Horizon oil spill and the response of species and food webs from this event. The resiliency of organisms to a spill can provide valuable insight to other events like a diversion. Invasive species may present a challenge as the diversion comes online and could increase competition for food and space. Some species will have the ability to temporarily move out of the system until conditions become favorable again, however, returning to baseline conditions could take time. Predator-prey interactions will most likely change or be affected in some way as organisms leave the estuary or certain prey communities shift. For example, different communities of zooplankton will dominate as salinities shift from saline to fresh and back. Dietary habits may change and generalist and opportunistic feeders may thrive in changing conditions compared to others that depend on a smaller range of prey.

In other parts of coastal Louisiana, such as the Breton Sound basin, current freshwater diversions have been studied to determine their effects on local estuarine food webs and can provide clues and insight into what could occur in Barataria Basin. Research has shown that diverting nutrient-rich freshwater into once cut-off wetland systems has increased primary productivity and the bottom-up forcing of the food web in Breton Sound (Wissel & Fry 2005). It has also been shown that the diversion in this region supports about 75 percent of the upper estuary food web (Wissel & Fry 2005). Freshwater pulses allow for the delivery of nutrients and basal resources into an estuarine habitat and also creates additional habitat for higher-level consumers that live or migrate in the area. In addition, those that move into the system to take advantage of this influx will in turn benefit even higher-level consumers. Though some species or groups of organisms may be pushed out of the system temporarily or even permanently, there is evidence in coastal Louisiana that some organisms will be drawn to the high-quality food source that the diversion creates, regardless of the less-than-optimal environmental conditions. Not all organisms that cannot tolerate fresher conditions will be completely driven away if high-quality food sources and nutrients are present (Piazza & La Peyre 2012).

Many gaps still exist and there is much research to be done to fully understand the dynamics of the food web in response to diversion operations. Several gaps were identified, among them the need to prioritize gaps within an effective monitoring plan and scientific research program that looks at effects before, during and after a diversion comes online. It is important that a baseline is established prior to any operational strategy that can be used as a comparison for future effects.

In summary, the food web dynamics of the Louisiana estuarine environment will change regardless of if a diversion is operated or not. Populations, habitats, and diversity will shift as subsidence and sea level rise alter the environment. Many of the species that may be positively affected by the diversion will also be negatively affected if no action is taken. Future conditions will have effects on the vegetation, fish and wildlife species and the natural resource users that rely on those species for sustenance or income. Diversion operational strategies should work with the environment to support the primary objective of building and sustaining land. According to past research, freshwater input will increase the overall abundance of primary and secondary productivity in the estuary and may result in an increase in fisheries catch, but much is still unknown on how the timing and duration of different operational strategies will affect this outcome (Rutherford et al. 2018).

BIBLIOGRAPHY:

Abbott, R.T. 1974. American Seashells; The Marine Molluska of the Atlantic and Pacific Coasts of North America. New York, NY. Van Nostrand Reinhold.

Adamack, A., C.S. Stow, D.M. Mason, L.P. Rozas, & T.J. Minello. 2012. Predicting the effects of freshwater diversions on juvenile brown shrimp growth and production: A Bayesian-based approach. Marine Ecology Progress Series, 444:155-173.

Allen, J.F. 1952. Observations on the biology, ecological relationships, and growth of the curved mussel, *Brachidontes recurvus (Rafinesque)*, in the upper Chesapeake Bay. Doctoral Dissertation: DP70053.

Allen, J. F. 1960. Effect of low salinity on survival of the curved mussel, Brachidontes recurvus. Nautilus 74: 1-8.

Arts, M.T. 1999. Lipids in freshwater zooplankton: selected ecological and physiological aspects. In Lipids in freshwater ecosystems. 71-90. Springer, New York, NY.

Baldwin, B.S. & R.I.E. Newell. 1995. Relative importance of different size food particles in the natural diet of oyster larvae (*Crassostrea virginica*). Marine Ecology Progress Series, 120:135-145.

Barros, N.B. & D.K. Odell. 1990. Food habits of bottlenose dolphins in the southeastern United States. Pp. 309-328, in The bottlenose dolphin (S. Leatherwood and R. R. Reeves, eds.). Academic Press, San Diego, California, 653 pp.

Barry, K.P. 2002. Feeding habits of blacktip sharks, Carcharhinus limbatus, and Atlantic sharpnose sharks, Rhizoprionodon terraenovae, in Louisiana coastal waters. LSU Master's Theses: 66.

Barry, K.P., R.E. Condrey, W.B. Driggers III & C.M Jones. 2008. Feeding ecology and growth of neonate and juvenile blacktip sharks *Carcharhinus limbatus* in the Timbalier-Terrebonne Bay complex, LA, USA. Journal of Fish Biology, 73:650-662.

Bejarano, A.C., R.S. Wells & D.P. Costa. 2017. Development of a bioenergetic model for estimating energy requirements and prey biomass consumption of the bottlenose dolphin *Tursiops truncatus*. Ecological Modelling, 356:162-172.

Berens McCabe, E., D.P. Gannon, N.B. Barros & R.S. Wells. 2010. Prey selection in a resident common bottlenose dolphin (*Tursiops truncatus*) community in Sarasota Bay, Florida. Marine Biology, 157(5):931-942.

Bianchi, T.S., R.L. Cook, E.M. Perdue, P.E. Kolic, N. Green, Y. Zhang, R.W. Smith, A.S. Kolker, A. Ameen, G. King, L.M. Ojwang, C.L. Schneider, A.E. Normand, & R. Hetland. 2011. Impacts of diverted freshwater on dissolved organic matter and microbial communities in Barataria Bay, Louisiana, U.S.A. Marine Environmental Research, 72:248-257.

Bonar, D.B., S.L. Coon, M. Walch, R.M. Weiner & W. Fitt. 1990. Control of oyster settlement and metamorphosis by endogenous and exogenous chemical cues. Bulletin of Marine Science, 46(2):484-498.

Brown, K.M. & T. D. Richardson. 1987. Foraging ecology of the southern oyster drill Thais haemastoma (Gray): constraints on prey choice . J. Exp. Mar. Biol. Ecol., 114:123-141.

Burlakova, L.E., D.K. Padilla, A.Y. Karatayev, D.N. Hollas, L.D. Cartwright & K.D. Nichol. 2010. Differences in population dynamics and potential impacts of a freshwater invader driven by temporal habitat stability. Biol Invasions, 12:927-941.

Butler. P.A. 1985. Synoptic Review of the Literature on the Southern Oyster Drill *Thais haemastoma floridana*. NOAA Technical Report NMFS 35, U.S. Dept. Comm, 9p.

Byers, J.E., W.G. McDowell, S.R. Dodd, R.S. Haynie., L.M Pintor & S.B. Wilde. 2013. Climate and pH predict the potential range of the invasive apple snail (*Pomacea insularum*) in the Southeastern United States. PLoS ONE 8(2):e56812.

Cake Jr., E.W. 1983. Habitat Suitability Index Models: Gulf of Mexico American Oyster. U.S. Department of the Interior Fish and Wildlife Service FWS/OBS-82/10.57.

Carlson, J.K. & I.E. Baremore. 2003. Changes in biological parameters of Atlantic sharpnose shark *Rhizoprionodon terraenovae* in the Gulf of Mexico: evidence for density-dependent growth and maturity. Marine and Freshwater Research, 54:227-234.

Castro, J.I. 1996. Biology of the blacktip shark, *Carcharhinus limbatus*, off the Southeastern United States. Bulletin of Marine Science, 59(3):508-522.

Chanley, P. E. 1958. Survival of some juvenile bivalves in water of low salinity. Proceedings of the National Shellfish Association 48:52-65.

Chen, Y. 2017. Chapter 9: Fish Resources of the Gulf of Mexico *In*: Burger, J., Y. Chen, W.E. Hawkins, K.R. Holzwart, W.R. Keithly Jr., R.M. Overstreet, K.J. Roberts, R.A. Valverde & B. Wursig. 2017. Habitats and Biota of the Gulf of Mexico: Before the Deepwater Horizon Oil Spill Volume 2: Fish Resources, Fisheries, Sea Turtles, Avian Resources, Marine Mammals, Diseases and Mortalities. New York, NY. Springer. DOI: 10.1007/978-1-4939-3456-0.

Coastal Protection and Restoration Authority of Louisiana (CPRA). 2017. Louisiana's Coastal Master Plan for a Sustainable Coast. CPRA, Baton Rouge, LA, USA.

"Conducting Large-Scale Wetland Restoration in Louisiana." *NOAA Fisheries*, www.fisheries.noaa.gov/national/habitat-conservation/conducting-large-scale-wetland-restoration-louisiana.

Das, A., D. Justic, & E. Swenson. 2010. Modeling estuarine-shelf exchanges in a deltaic estuary: Implications for coastal carbon budgets and hypoxia. Ecological Modelling, 221:978-985.

Das, A., D. Justic, M. Inoue, A. Hoda, H. Huang & D. Park. 2012. Impacts of Mississippi River diversions on salinity gradients in a deltaic Louisiana estuary: ecological and management implications. Estuarine, Coastal and Shelf Science, 111:17-26.

Deaton, L.E., W. Schmidt, B. Leblanc, J. Carter, K. Mueck & S. Merino. 2016. Physiology of the Invasive Apple Snail *Pomacea maculata*: Tolerance to Low Temperatures. Journal of Shellfish Research, 35 (1): 207-210.

Deegan, L.A. 1993. Nutrient and Energy Transport between Estuaries and Coastal Marine Ecosystems by Fish Migration. Canadian Journal of Fisheries and Aquatic Sciences, 50: 74-79.

De Guise, S., M. Levin, E. Gebhard, L. Jasperse, J.T. Saliki, L. Burdett Hart, C. Smith, S. Venn-Watson, F.I. Townsend, R.S. Wells, B.C. Balmer, E. Zolman, T.K. Rowles & L.H. Schwacke. 2017. Changes in immune functions in bottlenose dolphins in the northern Gulf of Mexico associated with the Deepwater Horizon oil spill. Endangered Species Research 33:291–303.

De Mutsert, K. & J.H. Cowan Jr. 2012. A Before-After-Control-Impact Analysis of the Effects of a Mississippi River Freshwater Diversion on Estuarine Nekton in Louisiana, USA. Estuaries and Coasts, 35(5):1237-1248.

Drymon, J.M., S.P. Powers, & R.H. Carmichael. 2012. Trophic plasticity in the Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) from the north central Gulf of Mexico. Environmental Biology of Fishes 95:21-35.

Duggan, M., R.M. Connolly, M. Whittle, G. Curwen, & M.A. Burford. 2014. Effects of freshwater flow extremes on intertidal biota of a wet-dry tropical estuary. Marine Ecology Progress Series 502:11-23.

Dugas, R. J., E. A. Joyce, and M. E. Berrigan. 1997. History and status of the oyster, Crassostrea virginica, and other molluscan fisheries of the US Gulf of Mexico. *MacKenzie, CL, Burrell Jr., VG, Rosenfield, A., Hobart, WL, eds* 187-210.

Farias-Sanchez, J.A. 1991. Ecology, culture, and utilization of the mussel, *Brachidontes recurvus (Rafinesque)*, in the context of an integrated management approach to Boca del Rio-Mandinga estuarine system, Veracruz, Mexico. Doctoral Dissertation: 234.

Fleeger, J.W. 1985. Meiofaunal Densities and Copepod Species Composition in a Louisiana, U.S.A., Estuary. Transactions of the American Microscopical Society 104(4):321-332.

Gedan, K.B., L. Kellogg and D.L. Breitburg. 2014. Accounting for multiple foundation species in oyster reef restoration benefits. Restoration Ecology 22(4):517–524.

Hawes, S.R. & H.M. Perry. 1978. Effects of 1973 Floodwaters on Plankton Populations in Louisiana and Mississippi. Gulf Research Reports 6(2):109-124.

Helenius, L.K., E. Leskinen, H. Lehtonen & L. Nurminen. 2017. Spatial patterns of littoral zooplankton assemblages along a salinity gradient in a brackish sea: a functional diversity perspective. Estuarine, Coastal and Shelf Science, 198:400-412.

Hornsby, F. E., T.L. McDonald, B.C. Balmer, T.R. Speakman, K.D. Mullin, P.E. Rosel, R.S. Wells, A.C. Telander, P.W. Marcy, K.C. Klaphake and L.H. Schwacke. 2017. Using salinity to identify common bottlenose dolphin habitat in Barataria Bay, LA. Endangered Species Research 33:181–192 doi: 10.3354/esr00807.

Higgs, J.M. 2016. Age, Growth, Reproduction, and Diet of the Finetooth Shark, *Carcharhinus isodon*, in the Northern Gulf of Mexico. Master's Thesis :173.

Honig, A., M. La Peyre, & J. Supan. 2014. Effects of low and high salinity regimes on seasonal gametogenesis of the ribbed mussel *Geukensia granosissima* in coastal Louisiana, USA. Sexuality and Early Development in Aquatic Organisms 1:75-82.

Honig, A., J. Supan, & M. La Peyre. 2015. Population ecology of the gulf ribbed mussel across a salinity gradient: recruitment, growth and density. Ecosphere 6(11):226.

"Hooked Mussel." *Chesapeake Bay Program*, www.chesapeakebay.net/S=0/fieldguide/critter/hooked_mussel.

Hopkins, S.H. 1954. *Cercaria brachidontis* N. Sp. from the Hooked Mussel in Louisiana. The Journal of Parasitology 40(1):29-31.

Hornsby, F.E., T.L. McDonald, B.C. Balmer, T.R. Speakman, K.D. Mullin, P.E. Rosel, R.S. Wells, A.C. Telander, P.W. Marcy, K.C. Klaphake, & L.H. Schwacke. 2017. Using salinity to identify common bottlenose dolphin habitat in Barataria Bay, Louisiana, USA. Endangered Species Research 33:181-192.

Ingole, B.S. & A.H. Parulekar. 1998. Role of salinity in structuring the intertidal meiofauna of a tropical estuarine beach: Field evidence. Indian Journal of Marine Sciences 27:356-361.

Jackson, C.R. & S.C. Vallaire. 2009. Effects of salinity and nutrients on microbial assemblages in Louisiana wetland sediments. Wetlands. 29(1):277-287.

Kang, S. & S.L. King. 2013. Effects of hydrologic connectivity on aquatic macroinvertebrate assemblages in different marsh types. Aquatic Biology 18:149-160.

Kang, S. 2011. Aquatic macroinvertebrate and nekton community structure in a Chenier marsh ecosystem: implications for Whooping Crane prey availability. LSU Doctoral Dissertation: 2136.

La Peyre, M.K., J. Geaghan, G. Decossas & J.F. La Peyre. 2016. Analysis of Environmental Factors Influencing Salinity Patterns, Oyster Growth, and Mortality in Lower Breton Sound Estuary, Louisiana, Using 20 Years of Data. Journal of Coastal Research 32(3):519-530.

Lane, S. M., C. R. Smith, B. C. Balmer, K. P. Barry, T. McDonald, J. Mitchell, C. S. Mori, P. E. Rosel, T. K. Rowles, T. R. Speakman, F. I. Townsend, M. C. Tumlin, R. S. Wells, E. S. Zolman and L. H. Schwacke. 2015. Reproductive outcome of bottlenose dolphins sampled in Barataria Bay, Louisiana, USA following the *Deepwater Horizon* oil spill. Proceedings of the Royal Society B. 282: 20151944.

Lee, R.F., Hagen, W. and Kattner, G., 2006. Lipid storage in marine zooplankton. Marine Ecology Progress Series, 307:273-306.

Leigh, S.C., Y.P. Papastamatiou & D.P. German. 2018. Seagrass digestion by a notorious 'carnivore.' Proceedings of the Royal Society B 285(1886).

Lichti, D.A., J. Rinchard & D.G. Kimmel. 2017. Changes in zooplankton community, and seston and zooplankton fatty acid profiles at the freshwater/saltwater interface of the Chowan River, North Carolina. PeerJ 5:e3667.

MacIntyre, H.L., R.J. Geider & D.C. Miller. 1996. Microphytobenthos: The Ecological Role of the "Secret Garden" of Unvegetated, Shallow-Water Marine Habitats. I. Distribution, Abundance and Primary Production. Estuaries 19(2A):186-201.

Martin, C.W. & J.F. Valentine. 2014. Tolerance of embryos and hatchlings of the invasive apple snail *Pomacea maculata* to estuarine conditions. Aquatic Ecology 48(3):321-326.

Melancon, E.J., Soniat T., V. Cheramie, R. Dugas, J. Barras & M. Lagarde. 1998. Oyster resource zones of the Barataria and Terrebonne stuaries. Journal of Shellfish Biology 17(4):1143-1148.

Melancon, E.J., B. Asrabadi & R.L. Chiasson. 2001. Salinity tolerance of the Hooked Mussel Ischadium recurum from Louisiana Waters. Louisiana Oyster Task Force report, La. Dept. Wild. & Fish. contract # 545050, 182p.

Montagna, P.A., R.D. Kalke, & C. Ritter. 2002. Effect of Restored Freshwater Inflow on Macrofauna and Meiofauna in Upper Rincon Bayou, Texas, USA. Estuaries, 25(68):1436-1447.

Muncy, R.J. 1984. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Gulf of Mexico): White Shrimp. U.S. Fish and Wildlife Service, Mississippi State, MS, USA.

Neer, J.A. & B.A. Thompson. 2004. Aspects of the Biology of the Finetooth Shark, *Carcharhinus isodon*, in Louisiana Waters. Gulf of Mexico Science 22(1).

Nixon, Scott W, & B.A. Buckley. (2002). “A strikingly rich zone”—nutrient enrichment and secondary production in coastal marine ecosystems. Estuaries, *25*(4):782-796.

O’Connell, M.T., T.D. Shepherd, A.M.U. O’Connell & R.A. Myers. 2007. Long-term Declines in Two Apex Predators, Bull Sharks (*Carcharhinus leucas*) and Alligator Gar (*Atractosteus spatula*), in Lake Pontchartrain, an Oligohaline Estuary in Southeastern Louisiana. Estuaries and Coasts 30(4):567-574.

Parsons, G.R. & E.R. Hoffmayer. 2015. Seasonal Changes in the Distribution and Relative Abundance of the Atlantic Sharpnose Shark *Rhizoprionodon terraenovae* in the North Central Gulf of Mexico. Copeia 4:913-919.

Perez, B.C., J.W. Day Jr., D. Justic, R.R. Lane & R.R. Twilley. 2011. Nutrient stoichiometry, freshwater residence time, and nutrient retention in a river-dominated estuary in the Mississippi Delta. Hydrobiologia 658(1):41-54.

Peyronnin, N.S., R. Caffey, J.H. Cowan Jr., D. Justic, A. Kolker, S. Laska, A. McCorquodale, E. Melancon Jr., J.A. Nyman, R. Twilley, J. Visser, J. Wilkins. 2016. Building Land in Coastal Louisiana: Expert Recommendations for Operating a Successful Sediment Diversion that Balances Ecosystem and Community Needs. www.MississippiRiverDelta.org/DiversionOpsReport.

Peyronnin, N.S., R.H. Caffey, J.H. Cowan Jr., D. Justic, A.S. Kolker, S.B. Laska, A. McCorquodale, E. Melancon Jr., J.A. Nyman, R.R. Twilley, J.M. Visser, J.R. White & J.G. Wilkins. 2017. Optimizing Sediment Diversion Operations: Working Group Recommendations for Integrating Complex Ecological and Social Landscape Interactions. Water, 9(6):368.

Piazza, B.P. & M.K. La Peyre. 2012. Measuring Changes in Consumer Resource Availability to Riverine Pulsing in Breton Sound, Louisiana, USA. PLoS ONE 7(5):e37536.

Poirrier, M.A. & C.E. Caputo. 2015. *Rangia cuneata* clam decline in Lake Pontchartrain from 2001 to 2014 due to an El Nino Southern Oscillation shift coupled with a period of high hurricane intensity and frequency. Gulf and Caribbean Research 26(1).

Pollard, J.F. 1973. Experiments to reestablish historical oyster seed grounds and to control the southern oyster drill. La. Dept. Wild. Fish., Tech. Rpt. No. 6, 82p.

Rakocinski, C.F., D.M. Baltz & J.W. Fleeger. 1992. Correspondence between environmental gradients and the community structure of marsh-edge fishes in a Louisiana estuary. Marine Ecology Progress Series 80:135-148.

Riekenberg, J., S. Bargu & R. Twilley. 2014. Phytoplankton community shifts and harmful algae presence in a diversion influenced estuary. Estuaries and Coasts 38(6):2213-2226.

Roller, R.A. & W.B. Stickle. 1989. Temperature and salinity effects on the intracapsular development, metabolic rates, and survival to hatching of *Thais haemastoma canaliculata* under laboratory conditions. Journal of Experimental Marine Biology and Ecology 125:235-251.

Rowe, G.T. 2017. Chapter 7: Offshore Plankton and Benthos of the Gulf of Mexico *In*: Byrnes, M.R., R.A. Davis Jr., M.C. Kennicutt II, R.T. Kneib, I.A. Mendelssohn, G.T. Rowe, J.W. Tunnell Jr., B.A. Vittor, & C.H. Ward. 2017. Habitats and Biota of the Gulf of Mexico: Before the Deepwater Horizon Oil Spill Volume 1: Water Quality, Sediments, Sediment Contaminants, Oil and Gas Seeps, Coastal Habitats, Offshore Plankton and Benthos, and Shellfish. New York, NY. Springer. DOI: 10.1007/978-1-4939-3447-8.

Rozas, L.P. & T.J. Minello. 2011. Variation in penaeid shrimp growth rates along an estuarine salinity gradient: Implications for managing river diversions. Journal of Experimental Marine Biology and Ecology, 397(2):196-207.

Rutherford, J.S., J.W. Day, C.F. D'Elia, A.R.H. Wiegman, C.S. Wilson, R.H. Caffey, G.P. Shaffer, R.R. Lane, & D. Batker. 2018. Evaluating trade-offs of a large, infrequent sediment diversion for restoration of a forested wetland in the Mississippi delta. Estuarine, Coastal and Shelf Science 203:80-89.

Schmoker, C., Russo, F., Drillet, G., Trottet, A., Mahjoub, M.S., Hsiao, S.H., Larsen, O., Tun, K. & Calbet, A. 2016. Effects of eutrophication on the planktonic food web dynamics of marine coastal ecosystems: The case study of two tropical inlets. Marine Environmental Research 119:176-188.

Schwacke, L. H., C. R. Smith, F. I. Townsend, R. S. Wells, L. B. Hart, B. C. Balmer, T. K. Collier, S. De Guise, M. M. Fry, L. J. Guillette Jr., S. V. Lamb, S. M. Lane, W. E. McFee, N. J. Place, M. C. Tumlin, G. M. Ylitalo, E. S. Zolman and T. K. Rowles. 2014. Health of common bottlenose dolphins (*Tursiops truncatus*) in the Gulf of Mexico following the *Deepwater Horizon* Oil Spill. Environmental Science & Technology 48:93-103.

Schwacke, L. H., L. Thomas, R. S. Wells, W. E. McFee, A. A. Hohn, K. D. Mullin, E. S. Zolman, B. M. Quigley, T. K. Rowles and J. H. Schwacke. 2017. Quantifying injury to common bottlenose dolphins from the *Deepwater Horizon* oil spill using an age-, sex- and class-structured population model. Endangered Species Research 33:265–279.

Short, J.W., H.J. Geiger, J.C. Haney, C.M. Voss, M.L. Vozzo, V. Guillory & C.H. Peterson. 2017. Anomalously High Recruitment of the 2010 Gulf Menhaden (*Brevoortia patronus*) Year Class: Evidence of Indirect Effects from the *Deepwater Horizon* Blowout in the Gulf of Mexico. Archives of Environmental Contamination and Toxicology 73(1):76-92.

Smith, C. R., T. K. Rowles, L. B. Hart, F. I. Townsend, R. S. Wells, E. S. Zolman, B. C. Balmer, B. Quigley, M. Ivančić, W. McKercher, M. Tumlin, K. Mullin, J. D. Adams, D. Wu, W. McFee, T. Collier, and L. H. Schwacke. 2017. Slow recovery of Barataria Bay dolphin health following the *Deepwater Horizon* Oil Spill (2013-2014), with evidence of persistent lung disease and impaired stress response. Endangered Species Research 33:127–142.

St. Amant, L.S. 1957. The southern oyster drill. Seventh Biennial Report to the Louisiana Wildlife & Fisheries Commission, p81-84.

Tunnell Jr., J.W. 2017. Chapter 8: Shellfish of the Gulf of Mexico *In*: Byrnes, M.R., R.A. Davis Jr., M.C. Kennicutt II, R.T. Kneib, I.A. Mendelssohn, G.T. Rowe, J.W. Tunnell Jr., B.A. Vittor, & C.H. Ward. 2017. Habitats and Biota of the Gulf of Mexico: Before the Deepwater Horizon Oil Spill Volume 1: Water Quality, Sediments, Sediment Contaminants, Oil and Gas Seeps, Coastal Habitats, Offshore Plankton and Benthos, and Shellfish. New York, NY. Springer. DOI: 10.1007/978-1-4939-3447-8.

Ulrich, G.F., C.M. Jones, W.B. Driggers III, J.M. Drymon, D.Oakley & C. Riley. 2007. Habitat Utilization, Relative Abundance, and Seasonality of Sharks in the Estuarine and Nearshore Waters of South Carolina. American Fisheries Society Symposium 50:125-139.

Urian, K.W., D.A. Duffield, A.J. Read, R.S. Wells and D.D. Shell. 1996. Seasonality of reproduction in bottlenose dolphins, *Tursiops truncatus*. Journal of Mammalogy 77:394-403.

VanderKooy, S.J. 2012. The Oyster Fishery of the Gulf of Mexico, United States: A Fisheries Management Plan - 2012 Revision. Publication No. 202, Gulf States Marine Fisheries Commission, Ocean Springs, MS.

Vieira, L.R., L. Guilhermino & F. Morgado. 2015. Zooplankton structure and dynamics in two estuaries from the Atlantic coast in relation to multi-stressors exposure. Estuarine, Coastal and Shelf Science 167:347-367.

Wells, R.S. 2014. Social structure and life history of common bottlenose dolphins near Sarasota Bay, Florida: Insights from four decades and five generations. Pp. 149-172 *In:* J. Yamagiwa and L. Karczmarski (eds.), Primates and Cetaceans: Field Research and Conservation of Complex Mammalian Societies, Primatology Monographs, Tokyo, Japan: Springer.

Wells, R.S., L.H. Schwacke, T.K. Rowles, B.C. Balmer, E. Zolman, T. Speakman, F.I. Townsend, M.C. Tumlin, A. Barleycorn & K.A. Wilkinson. 2017. Ranging patterns of common bottlenose dolphins (*Tursiops truncatus*) in Barataria Bay, Louisiana, following the *Deepwater Horizon* Oil Spill. Endangered Species Research 33:159-180.

Wells, R.S. & M.D. Scott. 2018. Bottlenose dolphin: Common Bottlenose Dolphin (*Tursiops truncatus*). Pp. 118-125 *In:* B. Würsig, J.G.M. Thewissen, and K. Kovacs, eds., Encyclopedia of Marine Mammals. 3rd Ed. Academic Press/Elsevier, San Diego, CA.

Windham, R.A. 2015. Rangia as Potential Indicators of Bay Health. Master's Thesis, Texas A&M University.

Wissel B. & B. Fry. 2005. Tracing Mississippi River influences in estuarine food webs of coastal Louisiana. Oecologia 144:659-672.

Wong, W.H., N.N. Rabalais & R.E. Turner. 2010. Abundance and ecological significance of the clam *Rangia cuneata* (Sowerby, 1831) in the upper Barataria Estuary (Louisiana, USA). Hydrobiologia 651:305-315.