Fall 12-20-2013

Assessing the Responses of Adult, Juvenile, and Larval Fish Assemblages to the Closure of the Mississippi River Gulf Outlet, an Artificial Tidal Pass in Southeastern Louisiana

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Recommended Citation

Cope, Rebecca Weatherall, "Assessing the Responses of Adult, Juvenile, and Larval Fish Assemblages to the Closure of the Mississippi River Gulf Outlet, an Artificial Tidal Pass in Southeastern Louisiana" (2013). *University of New Orleans Theses and Dissertations*. 1730.
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Assessing the Responses of Adult, Juvenile, and Larval Fish Assemblages to the Closure of the Mississippi River Gulf Outlet, an Artificial Tidal Pass in Southeastern Louisiana

A Thesis

Submitted to the Graduate Faculty of the
University of New Orleans
in partial fulfillment of the
requirements for the degree of

Master of Science
in
Earth and Environmental Sciences

By

Rebecca Weatherall Cope

B.A. University of Hawaii at Hilo, 2004

December 2013

Dedication

I would like to dedicate this manuscript to my parents, Thomas and Jennie Weatherall. Thank you for putting that mask on my face when I was a little girl and introducing me to the world below the sea. Thank you for fostering in me a sense of adventure and a love of the natural world. Most of all, though, thank you for always supporting me in all of my endeavors, and for always believing in me and helping me to believe in myself.

Acknowledgments

I would like to thank my advisor, Dr. Martin O'Connell, for his endless patience throughout my graduate career, and for his advice and support through it all. I would also like to thank my committee members Dr. Andrea Bourgeois-Calvin and Dr. Ioannis Georgiou for offering their advice and helping to make it through to the end. I would also like to say thank you to the members of the Nekton Research Lab. Thank you all for helping to get the larval sampling done when I could not be on the boat, and to Twyla Herrington Cheatwood for making sure it happened. Big, heartfelt thanks to my undergraduate workers for helping to pick through all those jellies and crabs, in particular Derik Gonzales and Arnaud Kerisit. Most of all, thank you to the "chief" of the NRL's field operations, Chris Schieble, for making it all possible. Thanks for teaching me all I needed to know, and for the mental support through it all.

I would like to thank the entire staff of the Lake Pontchartrain Basin Foundation. Your love and passion for the Lake were a great source of inspiration to me. Even though the water is not blue, you instilled in me a great appreciation of this amazing natural resource that I took for granted growing up in New Orleans. I would like to give thanks in particular to Anne Rheams who gave me a place in the LPBF family and who encouraged me to attend graduate school.

Above all, I would like to express my gratitude to my entire family. To my parents, thank you for being an endless source of love and support, and for making it all possible. To my husband Jason, thank you for standing by me and encouraging me to pursue my dreams, even when they seemed unreachable (and maybe a bit impractical). To my son Brayden Makai, thank you for always smiling and making me laugh when I felt I could not. And to my daughter Claire Josephine, even though you might have made this take a bit longer than planned, I would never change a thing. My love for you all is as deep as the ocean. Thank you for sticking with me to the end.

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Abstract

The creation of the Mississippi River Gulf Outlet (MRGO) in 1963 by the U.S. Army Corps of Engineers (USACE) represents one of the most catastrophic, anthropogenic stressors ever to impact the Lake Pontchartrain estuary in southeastern Louisiana, USA. The artificial tidal pass provided a direct route from the Gulf of Mexico to New Orleans. It allowed for high saline waters to enter Lake Pontchartrain, resulting in detrimental changes to the biotic community of the Lake and surrounding wetland areas. In July 2009, the USACE closed the MRGO in hopes of restoring natural ecosystems. This study assesses changes in the adult, juvenile, and larval fish assemblages in the Lake from data taken before and after the closure. Water quality data were also examined for shifts related to the MRGO closure. Significant decreases in salinity were found following the closure, however no significant differences were found in adult or larval fish assemblages.

Keywords: Mississippi River Gulf Outlet, Lake Pontchartrain, Louisiana, estuary, tidal pass, Gulf of Mexico, fish assemblages, larval, salinity

Introduction

Lake Pontchartrain Basin

Lake Pontchartrain is an oligohaline estuary in southeastern Louisiana. It has an area of 1,645 km^2 (Argyrou et al., 1997) with depths ranging from 0.5 m to 5.0 m (McCorquodale and Georgiou, 2004) and an average depth of 3.7 m (Li et al., 2008). Temperatures in the Lake range from 10^o C in the winter to approximately 30^o C in the summer (Georgiou and McCorquodale, 2002), and salinities generally range from 1 to 6 with a long-term mean of 4 (McCorquodale et al., 2009). The currents in Lake Pontchartrain are predominantly wind-driven, with major tidal influences limited to the tidal inlets (Georgiou and McCorquodale, 2002; Li et al., 2008; McCorquodale and Georgiou, 2004).

The major influence on the salinity regime of Lake Pontchartrain is freshwater input (Sikora and Kjerfve, 1985). Lake Pontchartrain is connected to Lake Maurepas to the west via Pass Manchac. Lake Maurepas is 241km^2 and receives input via the Blind, Amite, and Tickfaw rivers and other small streams (Sikora and Kjerfve, 1985; Argyrou et al., 1997). In turn, the majority of freshwater flowing into Lake Pontchartrain is from Lake Maurepas and the Tangipahoa River (O'Connell et al., 2004), with contributions also from the Tchefuncte River and several smaller rivers, including Cane Bayou and Bayous Castine, Lacombe, Bonfouca and Liberty. Flow from Lake Maurepas accounts for 76% of the freshwater coming into Lake Pontchartrain (Sikora and Kjerfve, 1985), and freshwater flow from the Tangipahoa River watershed accounts for 25% of riverine input (Turner, 1996). This represents about 5% of the volume of the tidal prism flowing through the tidal passes to the east (Swenson, 1981; Turner, 1996).

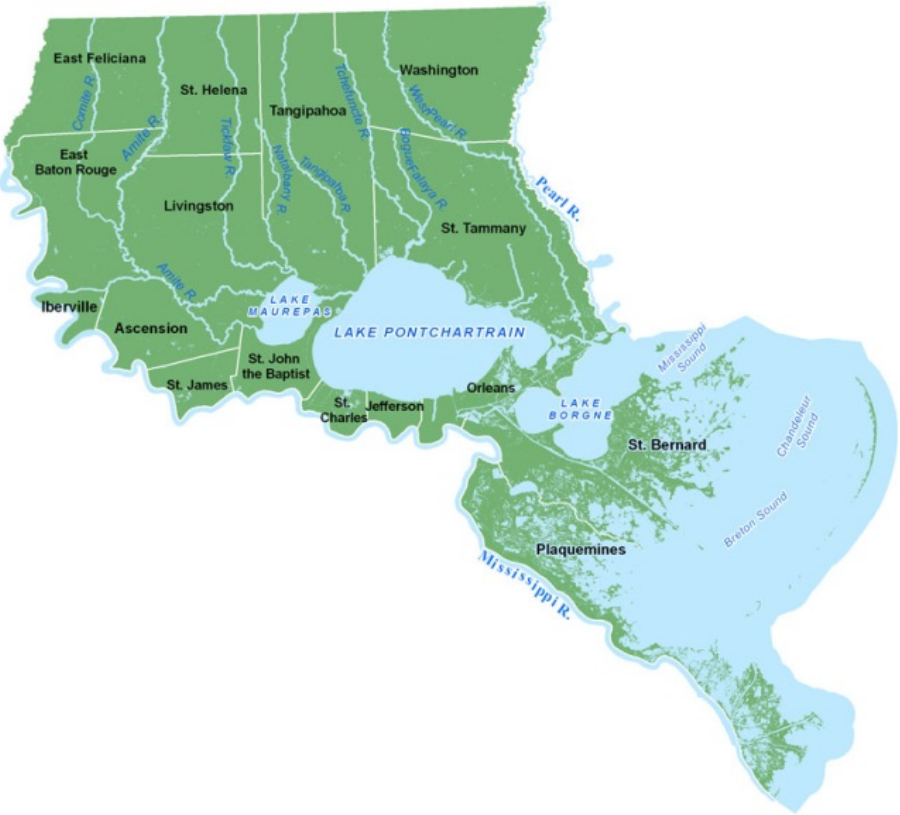


Figure 1: Map of the entire Lake Pontchartrain Basin with major rivers. The rivers contribute the bulk of freshwater input to Lake Pontchartrain (image from the Lake Pontchartrain Basin Foundation: www.saveourlake.org)

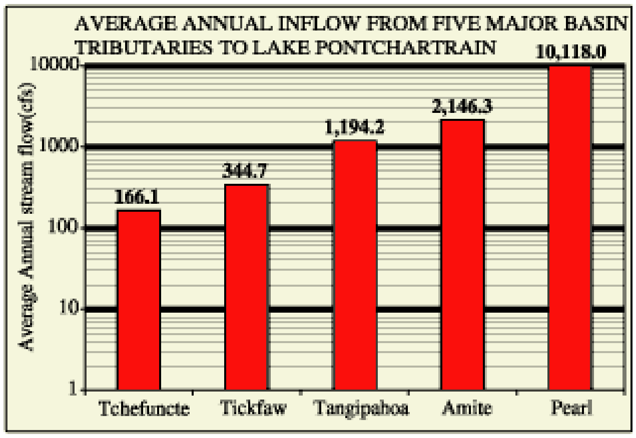


Figure 2: Annual freshwater contributions of each of the tributaries to Lake Pontchartrain. The influx from these waterways is a major source of fresh water in the Lake (McCorquodale et al., 2002).

Other sources of freshwater to Lake Pontchartrain include rain events and stormwater runoff to the south from the city of New Orleans (Turner, 1996; Argyrou et al., 1997; McCorquodale and Georgiou, 2004) and occasional opening of the Bonnet Carre Spillway 19 km (33 mi) upstream of New Orleans as a means of controlling flooding potential of the Mississippi River. The spillway is opened periodically when the Mississippi River water levels exceeds 12.5' (3.81 m) NGVD, which occurs on average every seven or eight years (Turner, 1996). This input can be significant, generally adding approximately 12,500 cfs (354 m^3/sec) to the annual freshwater inflow for that year (McCorquodale et al., 2002; Fig. 3). The most recent opening in May 2001 had peak flows >8,000 m^3/sec (USACE, 2011). There may also be some groundwater flow that directly enters Lake Pontchartrain, but this quantity is not known at this time. Sea-level rise and subsidence vary from 1 to 10 mm/year which may result in an annual change in the volume of the lake system of about 0.01 km^3 (McCorquodale et al., 2002).

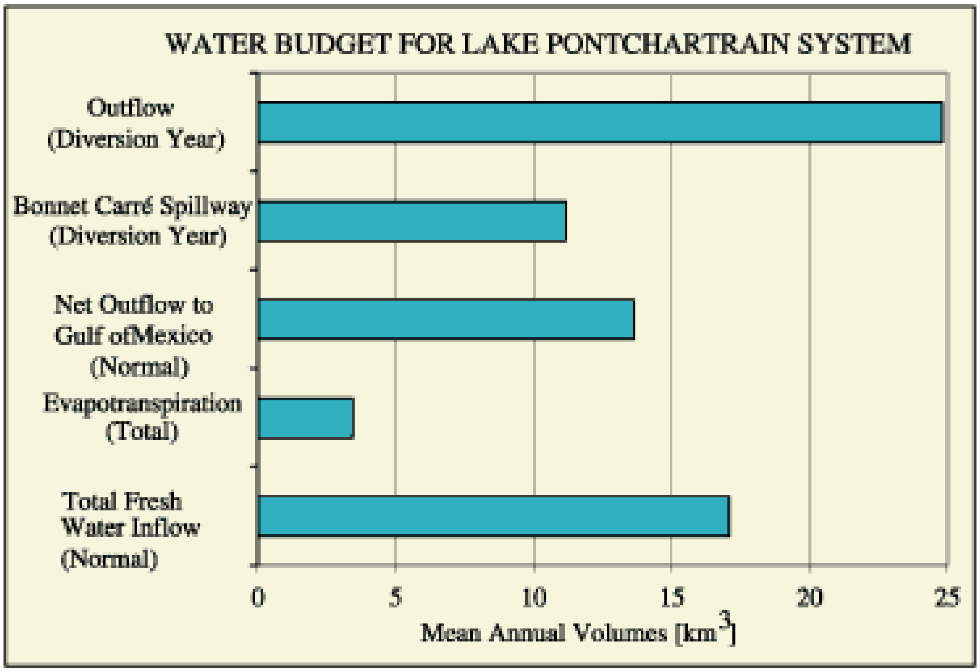


Figure 3: Water budget for the Lake Pontchartrain system (McCorquodale et al., 2002)).

Despite the large freshwater input, Lake Pontchartrain is not a freshwater lake, but rather an estuary with a salinity gradient. Salinity in the Lake ranges from 1 in the west to 6 in the east (McCorquodale et al., 2009). While freshwater flows into the Lake from the west, it currently receives saltwater input from Lake Borgne to the east via the two natural tidal passes: Rigolets Pass and Chef Menteur Pass. Lake Borgne, in turn, is open to the Gulf of Mexico. Rigolets Pass has a total length of 14.5 km, and an average depth of 8 m. Chef Menteur Pass has a total length of 11.3 m and an average depth of 13 m (Roblin, 2008). Additionally, Lake Pontchartrain received unnatural saltwater input from the Inner Harbor Navigation Canal (IHNC) through its connection to the Mississippi River Gulf Outlet (MRGO), prior to its closure in 2009 (Fig. 4).

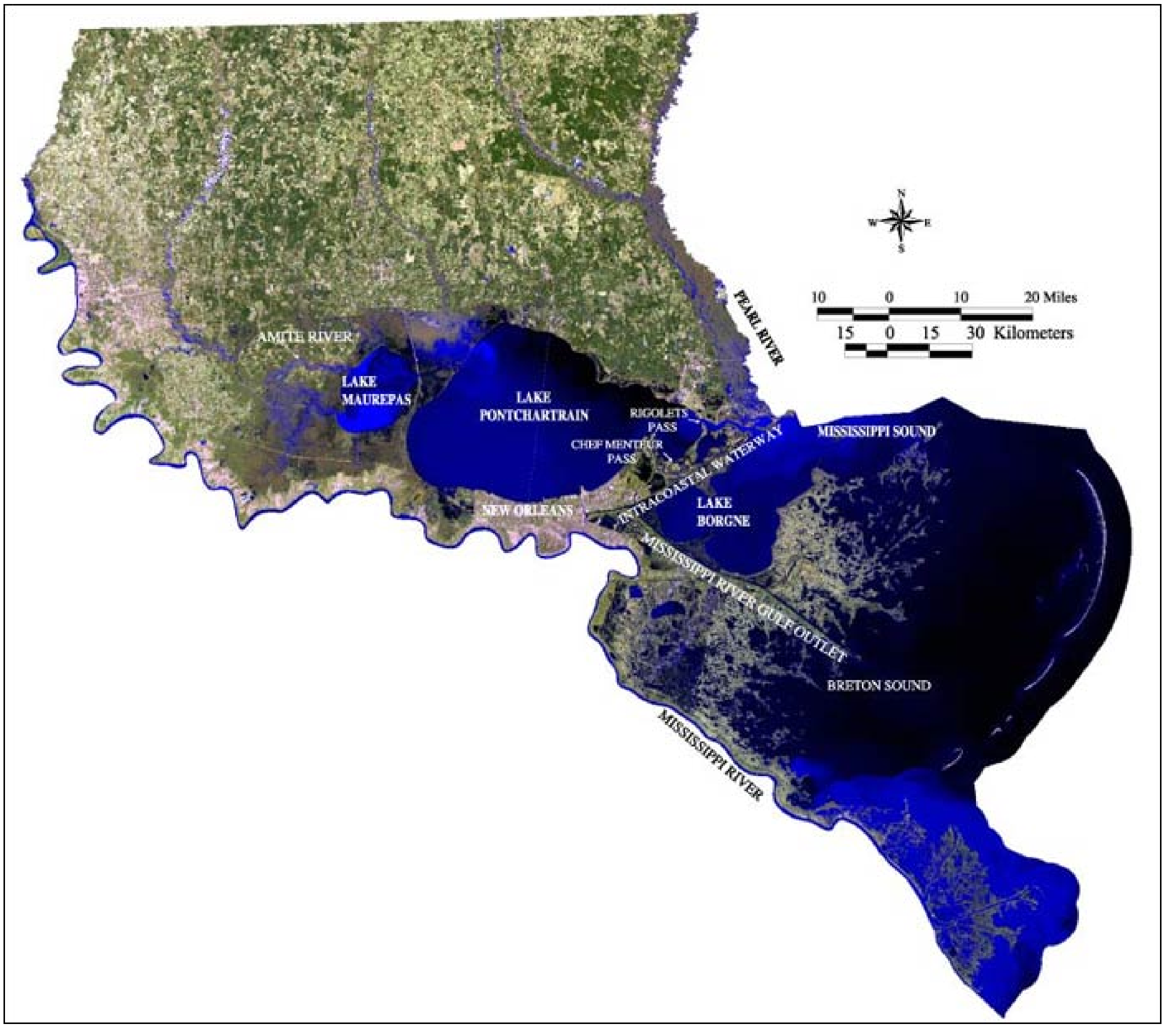


Figure 4: Satellite image of the Lake Pontchartrain Basin showing the location of Rigolets Pass, Chef Menteur Pass, and the Mississippi River Gulf Outlet. (Image from the Environmental Atlas of the Lake Pontchartrain Basin, 2002)

Due to small tidal ranges and the narrow passes, saltwater input is fairly low in the Lake (McCorquodale et al., 2009). Saltwater input through Rigolets Pass is also buffered somewhat due to freshwater discharge from the Pearl River just outside the pass in Lake Borgne (Sikora and Kjerve, 1985). Tidal exchange through the passes is 7800 m^3/s (Haralampides, 2000; Georgiou et al., 2009), with a tidal range of 3-45 cm. This represents about 0.00016% of the total volume of the Lake, which is about 4.75×10^9 m^3. While Lake Pontchartrain is a wind-dominated system with winds averaging 3 m/s (McCorquodale and Georgiou, 2004), the tidal currents through the passes are also influential at greater than 2 m/s during the flood tide (Li et al., 2008). There is a definite current pattern created by water entering and exiting through the passes as the water level in the Lake changes, with the strongest currents in the eastern part of the Lake nearest to the passes, and decreasing quickly towards the middle of the Lake (Signell and List, 2002; Fig. 5). The flow distribution of saltwater into Lake Pontchartrain is 64% through the Rigolets, 30% through Chef Menteur, and 6% through the IHNC via the MRGO and Gulf Intracoastal Waterway (GIWW) when the MRGO was still open (Georgiou et al., 2009).

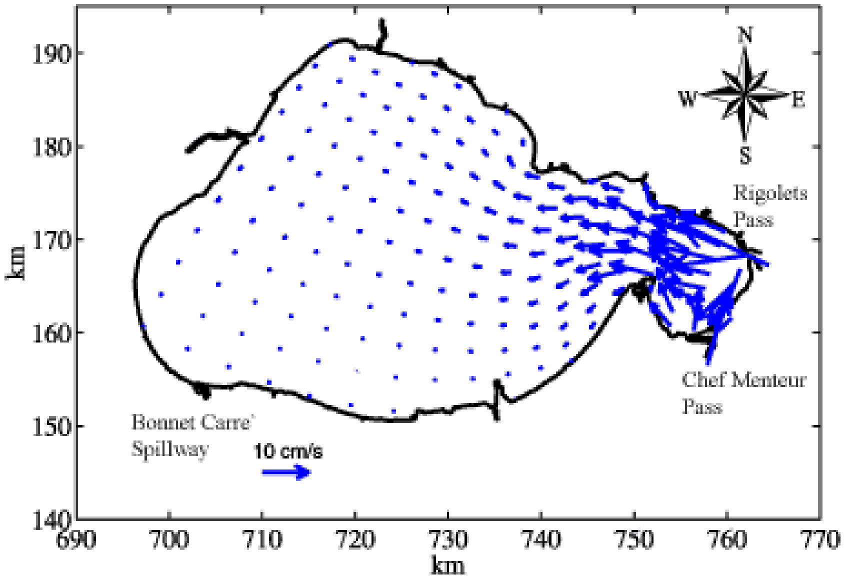


Figure 5: Current pattern created as water enters Lake Pontchartrain through the Rigolets Pass and Chef Menteur Pass. (Signell and List, 2002).

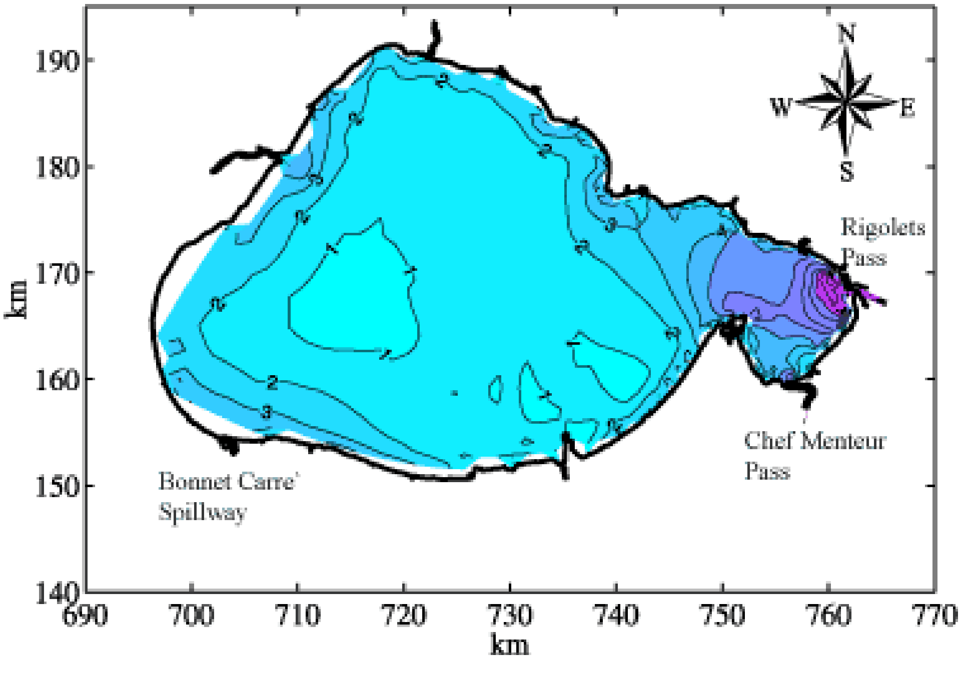


Figure 6: Average modeled current speed as water comes through the natural tidal passes into Lake Pontchartrain, with darker colors corresponding with faster currents coming through the passes into the east end of the Lake, and decreasing towards the center of the Lake, shown in lighter colors. (Signell and List, 2002)

Estuarine Systems

In the United States, estuarine systems make up about 80% of the Atlantic and Gulf of Mexico coasts (Emery, 1967; Boehlert and Mundy, 1988). Estuaries are dynamic environments offering primary habitats for various life stages of marine and aquatic organisms. Estuarine habitats offer protection from predators as well as an abundance of food. Estuaries are highly productive environments that support a high abundance of organisms. It has been estimated that 98% of seafood harvested in the Gulf of Mexico is dependent on Louisiana's estuaries (Yates, 1999). The tidal passes play an important role in this function by facilitating movement between the estuary and the ocean. This is important for organisms moving in and out of an estuary for feeding and reproductive purposes. Many estuarine-dependent species live out most of their life cycle in the estuary where they serve as an important link in the food web. While larval organisms feed on other plankton, they are also a prey item for many fish species, thereby serving as a means of energy transfer in the system (Hill et al., 1989). Estuarine-dependent fish and invertebrates will often spawn offshore, and then the eggs drift back toward the estuary in surface currents. Timing generally is such that the eggs hatch once they are near shore, and then the larvae begin their migration into the estuary, often utilizing tidal passes. Many different factors control the movement of larval organisms from the ocean to the estuary (Brown et al., 2004). There are many different stimuli from estuaries that may induce behavioral responses by larvae which enable them to move toward inlets. These include salinity, current speed, temperature, turbidity, olfactory cues, bottom composition, and lunar phase (Boehlert and Mundy, 1988). There are different mechanisms by which larvae accomplish their movement through tidal inlets and into the estuary. For example, as many larval organisms reach nearshore areas, they begin to exhibit locomotion which enables them to regulate their vertical position in the water column. By moving up and down in the water column, the larvae ensure their transport into the estuary with the tides, a behavior known as “selective tidal stream transport” (STST). During the flood tides, they position themselves in the upper portion of the water column, thereby moving into the estuary. During ebb tides, they move down towards the bottom where the water is still moving inland (Forward et al., 2003; Fig. 7). Some species, such as ovigerous female Blue Crabs (*Callinectes sapidus*) similarly utilize STST to make their way out of the estuary then to return (Forward et al. 2003). As they enter the estuary, the zoea respond to chemical cues and lowered salinity causing them to transform into the settling stage, at which time they are called megalopae. During this stage, the crabs settle out in areas of submersed aquatic vegetation (SAV) or in the marsh where they are able to grow in a more protected environment (Etherington and Eggleston 2000).

Salinity has also been shown to be one controlling factor in the orientation of Red Drum *(Sciaenops ocellatus)* larvae within the water column. Studies of *S. ocellatus* larvae have shown that incoming eggs drop down in the water column once the salinity falls below 25. Above 25, their eggs remain buoyant (Brown et al., 2004). Studies specifically on crustaceans have shown responses to salinity changes. It has been demonstrated that penaeid shrimp alter their position in the water column in response to salinity changes, thereby either allowing the larvae to move into the estuary, or the juveniles to move out. Specifically, lowered salinity induces benthic orientation of larvae and “negative rheotaxis”, or movement away from the current, by juveniles. Increased salinity cued swimming behavior in larvae and “positive rheotaxis” (movement in the direction of the current) in juveniles (Hugh 1969; Boehlert and Mundy, 1988). This responsive behavior allows for the retention of larvae within the estuary or the emigration of juveniles out of the estuary. Similarly, during emigration from the estuary, juvenile swimming crabs

(*Macropipus holsatus)* have been shown to swim in response to decreased salinity, which results in their net movement out of the estuary (Venema and Creutzberg, 1973; Boehlert and Mundy, 1988).

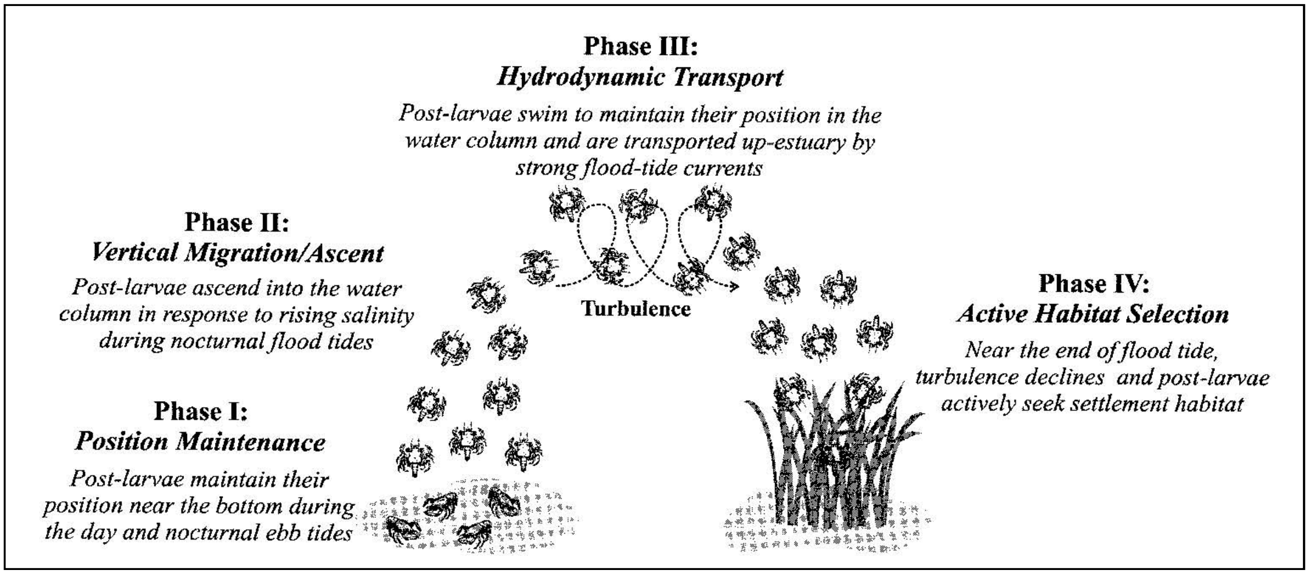


Figure 7. Utilization of selective tidal-stream transport (STST) by crab larvae to facilitate movement into the estuary. (Image from Forward et al. 2003)

Salinity alone, though, is not the only important factor related to the movement of organisms in and out of the estuary. Temperature tolerances of different organisms may influence their distribution, as well as turbulence, turbidity and light. Atlantic Menhaden (*Brevoortia patronus*), for example, prefer turbulent water and thus seek shallow water and tidal creeks (Fore and Baxter, 1972; Boehlert and Mundy, 1988). The ability of fishes to detect current speeds even in larval forms may also influence their position within the water column as a means of entering or exiting an estuary (Iwai, 1967). Many studies have been conducted on the roles of behavioral and physical factors lending to recruitment, and most have determined that it is a combination of the two that ultimately determine the fate of larvae. More specifically, it has been found that larval behavior is in response to physical stimuli, including temperature, turbidity, lunar phase, bottom composition, current speed, olfactory cues, and also salinity. These physical factors may act as “point source” stimuli that influence the short-term behavioral responses of larvae. These physical factors act in concert with one another to influence larval recruitment into an estuary, and it has been suggested that caution be used when attempting to describe cause and affect relationships between recruitment and single variables, such as salinity here. Seemingly positive correlations may in fact not be real (Boehlert and Mundy, 1988). It is important to look at the suite of factors involved.

The Lake Pontchartrain Estuary

The Lake Pontchartrain estuary provides suitable nursery habitat for larval and subsequent juvenile forms. Within Lake Pontchartrain SAV provides excellent habitat for young fishes and invertebrates. These SAV beds have been designated by the Magnuson-Stevens Fishery Conservation Act of 1996 as essential fish habitat due to the reliance of many different organisms on the presence of SAV (Cho and May, 2006). As a nursery habitat, SAV provides an abundance of food and protection from predation (Cho and Poirrier, 2002). Competent larval fish and invertebrates migrating into estuaries commonly settle in SAV beds, where they are able to grow in size before moving out into the more open environment (Brown et al., 2004).

The Lake provides both recreational and commercial opportunities for the human population living in the Pontchartrain Basin, although the Lake has suffered from environmental degradation over the past half century due to anthropogenic impacts. These have included urbanization (particularly on the south shore), a large shell dredging industry until the 1990s, shoreline impoundment on the south shore, overfishing, stormwater and agricultural runoff, sewage input, and unnatural saltwater intrusion (Penland and Maygarden, 2002; O'Connell et al., 2006; Fig. 8; Fig. 9; Table 1). Presently, an increase in development on the north shore of Lake Pontchartrain is causing many of the same problems previously produced on the south shore (Fig. 10). In particular, there are large areas of wetland habitat being destroyed as the area shifts from rural to a more suburban setting and the human population increases.

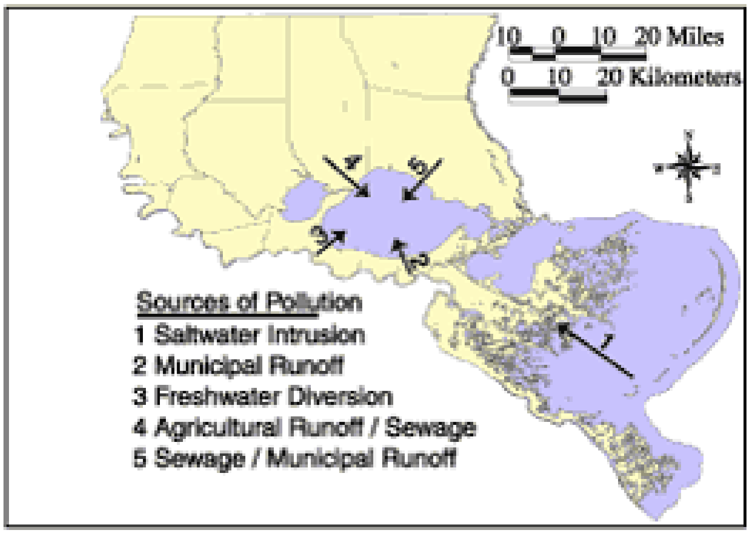
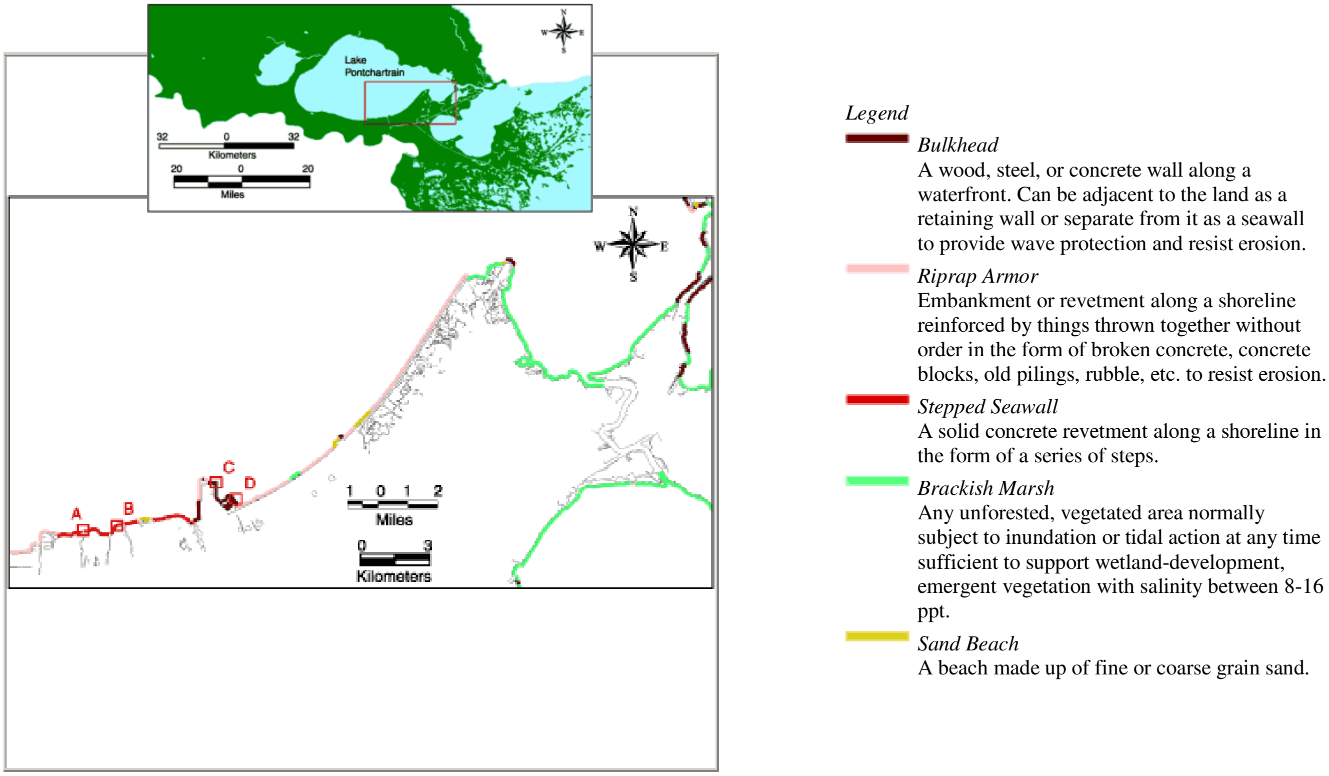


Figure 8. Environmental stressors impacting the Pontchartrain Basin (Penland and Maygarden, 2002).

Table 1: Total amounts of the various shoreline types found around Lake Pontchartrain. These include both natural and artificial shoreline types (Beall et al., 2002).

Shoreline Type	**Miles**
Bulkhead	11.8
Riprap	34.6
Seawall	4.3
Sand beach	8.6
Shell Beach	0.3
Fresh Marsh	1.8
Intermediate Marsh	5.9
Brackish Marsh	30.1
Natural Bank	0.1
Swamp	22.8
Swamp & Fresh Marsh	4.6
Swamp & Intermediate Marsh	0.3
Swamp & Brackish Marsh	0.1
Total	125.3



Legend

Bulkhead
A wood, steel, or concrete wall along a waterfront. Can be adjacent to the land as a retaining wall or separate from it as a seawall to provide wave protection and resist erosion.

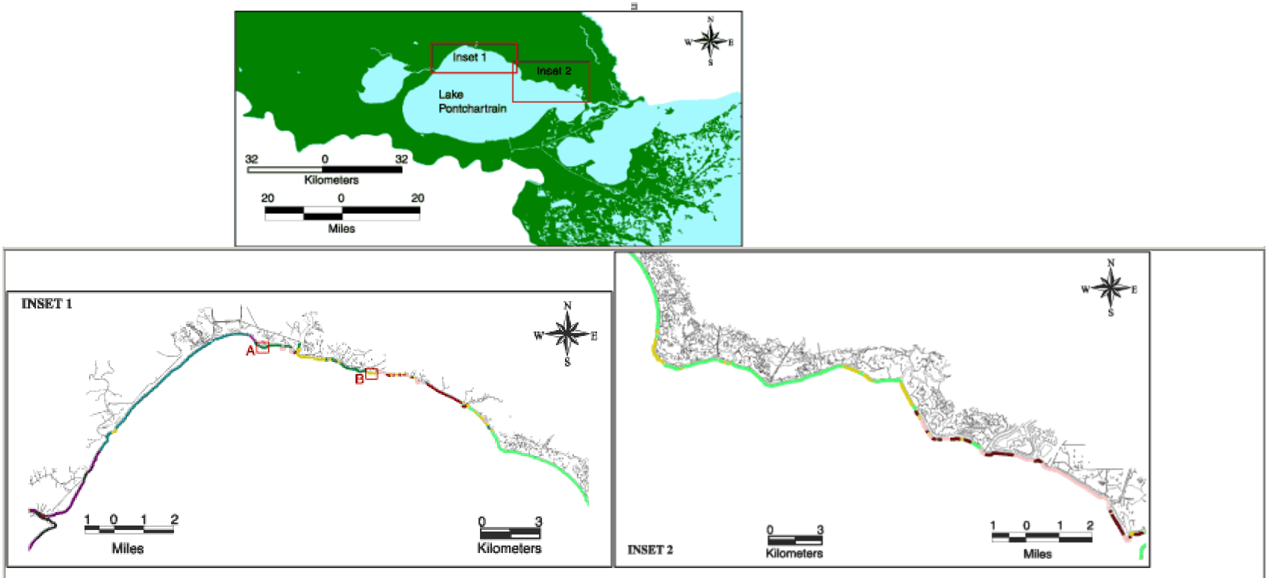
Riprap Armor
Embankment or revetment along a shoreline reinforced by things thrown together without order in the form of broken concrete, concrete blocks, old pilings, rubble, etc. to resist erosion.

Stepped Seawall
A solid concrete revetment along a shoreline in the form of a series of steps.

Brackish Marsh
Any unforested, vegetated area normally subject to inundation or tidal action at any time sufficient to support wetland-development, emergent vegetation with salinity between 8-16 ppt.

Sand Beach
A beach made up of fine or coarse grain sand.

Figure 9. Different shoreline types of the southeast shore of Lake Pontchartrain are shown in the above figure. This gives an idea of the extensive amount of shoreline modification in the New Orleans area of the Lake, which includes bulkheads, rip rap, and seawalls. There are small amounts of natural features remaining, including brackish marsh and sand beach (Beall et al., 2002).



Legend

▬ *Swamp*
Any forested area normally subject to inundation through part of the growing season or with permanent or near-permanent standing water.

▬ *Swamp with Fresh Marsh*
An area of swamp at the shoreline that contains a fresh marsh (salinity less than 0.5 ppt) behind the shoreline.

▬ *Swamp with Intermediate Marsh*
An area of swamp at the shoreline that contains a fresh marsh (salinity between 0.5-8 ppt) behind the shoreline.

▬ *Fresh Marsh*
Any unforested, vegetated area normally subject to inundation or tidal action at any time sufficient to support wetland-dependent, emergent vegetation with salinity less than 0.5 ppt.

▬ *Intermediate Marsh*
Any unforested, vegetated area normally subject to inundation or tidal action at any time sufficient to support wetland-development, emergent vegetation with salinity between 0.5-8 ppt.

▬ *Brackish Marsh*
Any unforested, vegetated area normally subject to inundation or tidal action at any time sufficient to support wetland-development, emergent vegetation with salinity between 8-16 ppt.

▬ *Riprap Armor*
Embankment or revetment along a shoreline reinforced by things thrown together without order in the form of broken concrete, concrete blocks, old pilings, rubble, etc. to resist erosion.

▬ *Shell Beach*
A beach of high relief made up predominately of shell.

▬ *Sand Beach*
A beach made up of fine or coarse grain sand.

▬ *Bulkhead*
A wood, steel, or concrete wall along a waterfront. Can be adjacent to the land as a retaining wall or separate from it as a seawall to provide wave protection and resist erosion.

Figure 10. The different shoreline types of the north shore of Lake Pontchartrain. These include both natural and artificial features, as described above. Compared to the south shore of the Lake, the north shore is still comprised of more natural features, although these are declining with increased development in the area (Beall et al., 2002).

These anthropogenic impacts have caused many different environmental concerns throughout the Pontchartrain Basin. For example, almost 200,000 acres of Pontchartrain Basin wetlands were lost between 1932 and 1990 as a result of urbanization, which included the building of flood control structures such as levees, dredging, filling and channelization, and subsequent shoreline erosion along with natural subsidence. Within the Lake itself, an estimated 75% of the SAV died off between 1940 and 1990 (Penland and Maygarden, 2002). The growth of SAV serves as reliable indicator of water quality in a given water body. This has certainly held true in Lake Pontchartrain, which had fairly extensive SAV beds until the second half of the twentieth century. A 1954 assessment of SAV within the Lake found a continuous meadow extending out from the north shore to a depth of 2 m, as well as an abundance of SAV along the south shore (Suttkus et al, 1954; Cho and Poirrier, 2002). Unfortunately, the increase of detrimental anthropogenic activities around and within the Lake affected the SAV along with other important biological resources. Between 1954 and 1973 the abundance of SAV had declined by 25-35% (Turner et al., 1980). From there, it declined another 50% by 1984 and 17% by 1992 (Mayer, 1986; Burns et al., 1993; Cho and Poirrier, 2002). Following the ban on shell dredging in 1990, however, the SAV beds within Lake Pontchartrain began to recover, and by the year 2000 had rebounded to a historical high (Cho and Poirrier, 2002; Fig. 11). Additionally, the shell dredging industry within Lake Pontchartrain, which targeted the *Rangia cuneata* clams (often referred to simply as *Rangia* clams), began in 1933 and quickly grew. At one point, more than 4 million m^3 of clams were extracted annually, causing a severe decline in the population of this important keystone species (Sikora and Kjerfve, 1985).

Figure 11. Distribution of submersed aquatic vegetation (SAV) with study areas listed in 2000. Abundant: SAV foliage covered at least 30% of the grassbed area; Common: SAV foliage covered approximately 10 to 30% of the grassbed area; Infrequent: SAV foliage covered at most 10% of the grassbed area (image from Cho and Poirrier, 2002)

Fish assemblages in the Lake have also changed over the years as a result of these anthropogenic influences, with fish production declining by 49% as a result of wetland destruction between 1900 and 1980 (Stone, 1980). This, however, did not keep fishing pressure to a minimum, as the commercial catch continued to increase (Penland et al., 2002). Estuarine fishes have been more greatly impacted than other fishes, as their life cycles are dependent on the habitat provided by such estuaries. For example, Atlantic Croaker (*Micropogonias undulatus*) showed greater declines than other fishes during the years of shell dredging (O'Connell et al., 2004; Chavez-Lopez et al., 2005). Estuaries, of course, change over time as a result of natural factors, such as subsidence and wetland loss due to delta deterioration, and major storms and hurricanes which produce both short and long-term change. Human-induced environmental change, however, is unfortunately much more significant in the Lake Pontchartrain estuary, particularly on the south shore of the Lake where the human population is concentrated (Barbe and Poirrier, 1991). If degradation of the ecosystem does not cease, the primary nursery habitat in the region on which fish rely will continue to diminish, and overall fish production could experience significant declines (Penland et al., 2002).

Despite these impacts, the Lake Pontchartrain estuary is again a productive ecosystem that is home to a wide range of fishes, birds, plants, and animals. The turn-around of the Lake is due in large part to the efforts of the Lake Pontchartrain Basin Foundation (LPBF). The LPBF was established in 1989 as a non-profit organization devoted to the revitalization of the entire Lake Pontchartrain Basin, following the citizen-led "Save Our Lake" campaign. At the time of the Foundation's creation, the Lake was in terrible condition due to its history of anthropogenic impacts. In addition to the ecological concerns mentioned above, recreational activities that once abounded were no longer an option due to the poor water quality. Nearshore conditions were so reduced that the public beaches were no longer useable and swimming anywhere was not recommended. The establishment of the LPBF was the beginning of a true effort to bring back the Lake to acceptable conditions. The ban of shell dredging in 1990 within the Lake was the Foundation's first major victory. Through the efforts of LPBF's "Save Our Lake" campaign coupled with the work of government agencies, water quality was improved and the Lake became useable again. As conditions have improved, LPBF has expanded its role to include the entire Lake Pontchartrain Basin watershed and estuary. Today, the Foundation is making strides throughout the basin, with projects in the Lake, the north shore rivers, coastal wetlands, and Bayou St. John to name a few.

Mississippi River Gulf Outlet

While the Lake Pontchartrain estuary has been altered by the various anthropogenic impacts discussed, saltwater intrusion from the Gulf of Mexico via MRGO has possibly been the greatest stressor (Barrett, et al., 1990; O'Connell et al., 2004). The MRGO was complete by the U.S. Army Corps of Engineers (USACE) in January of 1968 to provide a deep-draft shipping channel with a direct route between the Gulf of Mexico and New Orleans (Fig. 12). It is 120 km long, 157 m wide and 11 m deep (Sikora and Kjerfve, 1985). The channel allowed the high saline waters of the Gulf to move directly up to New Orleans with tides and storm events. The resulting saltwater intrusion has led to severe wetland losses in the surrounding areas. Thousands of acres of marshes and bald cypress swamps have suffered mortality due to both the dredging of the channel and also their intolerance to increases in salinity that followed. These natural resources provided priceless protection against tropical storms and hurricanes by effectively buffering storm surge. It has been noted that bald cypress-water tupelo swamps offer much greater protection from storm surge and wind damage than other types of wetland habitats.

Prior to the construction of the MRGO, the 10 km of wetlands that existed between St. Bernard and Orleans parishes and Lake Borgne had a storm surge reduction capacity of 1.35 m (Shaffer et al., 2009). Adding to this the fact that a large amount of this wetland habitat consisted of bald cypress-water tupelo swamp, the reduction capacity actually would have been much larger. These wetlands suffered widespread mortality from saltwater intrusion when the USACE cut through the natural ridge at Bayou LaLoutre during the construction of the MRGO (Van Heerden et al., 2007; Shaffer et al., 2009). The loss of these wetlands, in addition to the almost 200,000 acres already lost since 1932 in the entire Pontchartrain Basin, has been extremely detrimental to the biota of the region, as well as the human population (Penland and Maygarden, 2002).

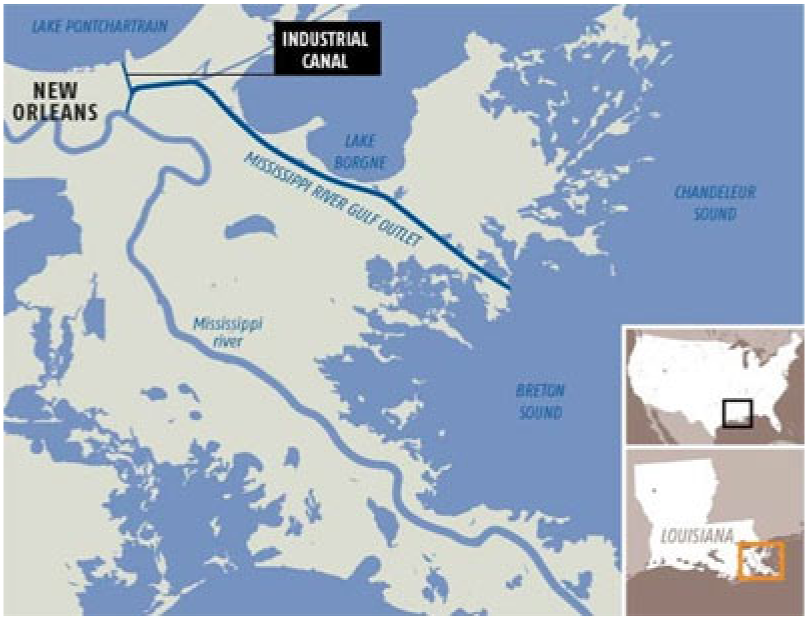


Figure 12. The route of the MRGO from the Gulf of Mexico to Lake Pontchartrain (image from the USACE website, www.mrgo.gov)

There was great opposition to the U.S. Army Corps of Engineers' plans for the MRGO as early as the 1950s, particularly by the U.S. Fish and Wildlife Service and the Louisiana Department of Wildlife and Fisheries. Despite this, there were very few studies commissioned by the USACE on the possible outcomes of such an environmental modification and the few that were completed were ignored. One of these studies predicted salinity increases of 4-6, which scientists knew would result in wetland mortality. Unfortunately, such cautions went unheeded and the construction of the MRGO ensued. The USACE, however, was not entirely ignorant of the destruction that would result based on projected outcomes from reports and statements of the USACE. These included such effects as marshland losses from dredge material deposition of 65.49 km^2 initially, 71.22 km^2 of disposal areas which would have deleterious effects on aquatic species, impacts to an additional 42.94 km^2 with each subsequent dredge operation, water turbidity increases, impacts to demersal biota, disruptions of natural hydrology, resolubilization of chemicals, and impacts to local plant species (USACE, 1976; Shaffer et al., 2009). The USACE justified the projected damages with the expected economic benefits of the new channel. In reality, though, the MRGO never paid off as the majority of shipping traffic still found the Mississippi River the preferred route to the city. Only 1-4 ships per day actually utilized the channel, representing about 3% of the shipping to the Port of New Orleans. This small benefit was far outweighed by the $10 million a year in dredging maintenance costs and additional costs of emergency repairs which together added up to half a billion dollars over the life of the project. When factoring in resulting hurricane destruction over the years due to wetland loss, and most recently by Hurricane Katrina's path straight up the MRGO, the total costs are well into the hundreds of billions of dollars (Shaffer et al., 2009). This does not even factor in impacts to fisheries.

Most knowledge of the Lake Pontchartrain fauna prior to the MRGO construction comes from studies published by Darnell (1959, 1962), however these lack detailed information. The only known comprehensive fisheries survey commissioned before the MRGO construction focused on the Biloxi Marshes and did not include the immediate resources of Lake Pontchartrain (Rounsefell, 1964). The results discussed the possible ecological responses in relation to the projected 4-6 increase in salinity. It was thought that this increase would eventually make Lake Pontchartrain saltier than Lake Borgne. Actual salinity increases were fortunately less than these original projections. One study conducted in Lake Pontchartrain found salinity increases of 0.2 to 2 following the completion of the MRGO (Sikora and Kjerfve, 1985). That said, the conclusions pointed to large deleterious impacts to the naturally-occurring biota of the area. Furthermore, it was noted that water control structures at the intersection of the MRGO and the IHNC would help to regulate salinity levels (Rounsefell, 1964). These proposed structures were never built. In the end, the changes in hydrology and salinity regimes did affect the organisms in Lake Pontchartrain with significant negative consequences (Sikora and Kjerfve, 1985; O'Connell et al., 2004; O'Connell et al., 2006; Shaffer et al., 2009).

The IHNC was shown to allow plumes of saltwater from the MRGO into Lake Pontchartrain which periodically covered large areas (<250 km^2) of the Lake bottom (Georgiou and McCorquodale, 2002; McCorquodale and Georgiou, 2004; Georgiou et al., 2009). These large plumes can be visible in satellite imagery (Fig. 13). Due to the shallow nature of Lake Pontchartrain, it is generally well-mixed (Sikora and Kjerve, 1985). The consistent saltwater input, however, resulted in stratification of the waters near the entrance to the IHNC, with the bottom layer containing waters with salinities greater than 20 (Georgiou and McCorquodale, 2002; Fig. 14; Fig. 16). Without mixing with the upper layer, this salinity gradient has been found to cause a zone of low dissolved oxygen in the area, with hypoxia during the summer months (Poirrier, 1978; McCorquodale and Georgiou, 2004; Georgiou et al., 2009; Fig. 15; Fig. 17). Strong stratification has also been recorded during the winter months due to storms and cold temperatures, however at this time of year the dead zone does not appear (McCorquodale and Georgiou, 2004).

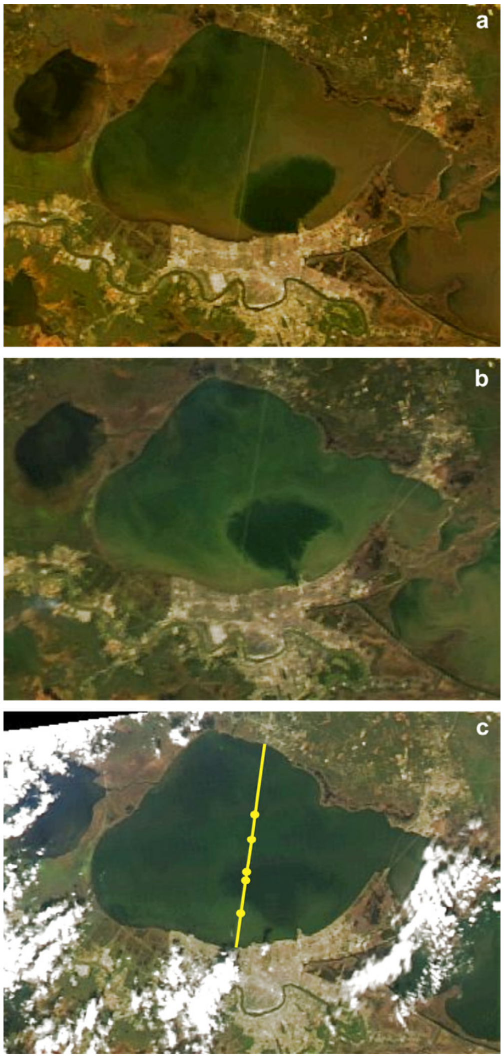


Figure 13. MODIS imagery showing the saltwater plume emanating from the mouth of the IHNC into Lake Pontchartrain (Li et al. 2008).

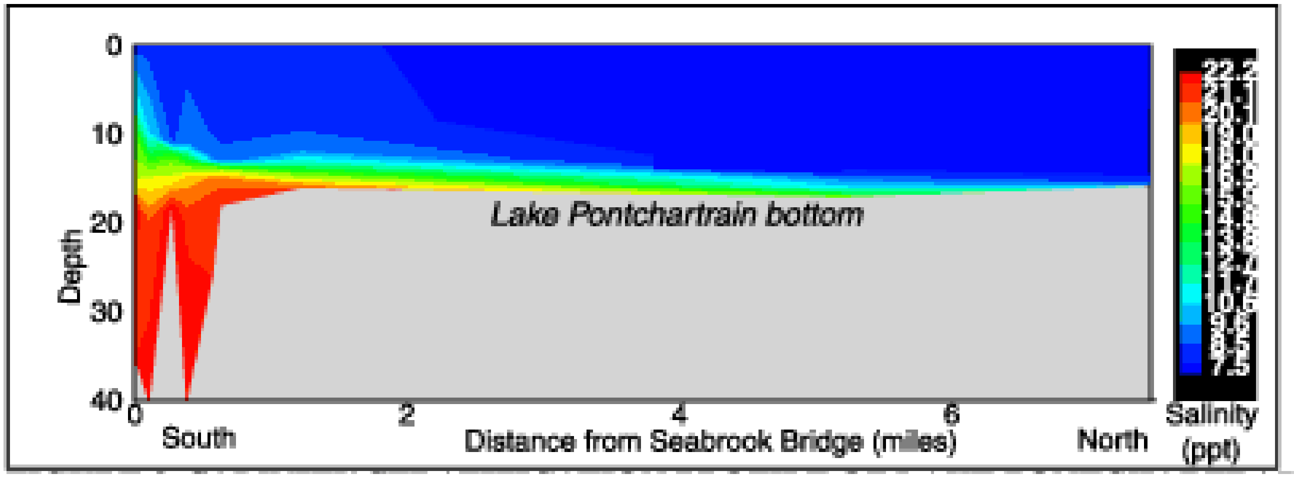


Figure 14. Salinity stratification profile of Lake Pontchartrain in the vicinity of IHNC as a result of saltwater intrusion from the MRGO (Georgiou and McCorquodale, 2002).

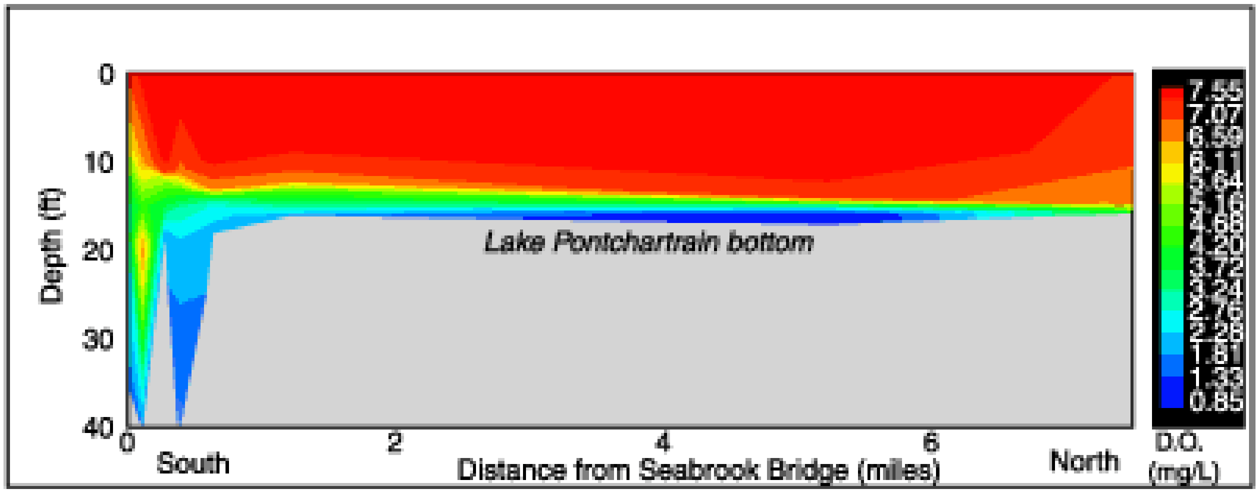


Figure 15. Dissolved oxygen stratification profile of Lake Pontchartrain in the vicinity of IHNC as a result of saltwater intrusion via the MRGO (Georgiou and McCorquodale, 2002)

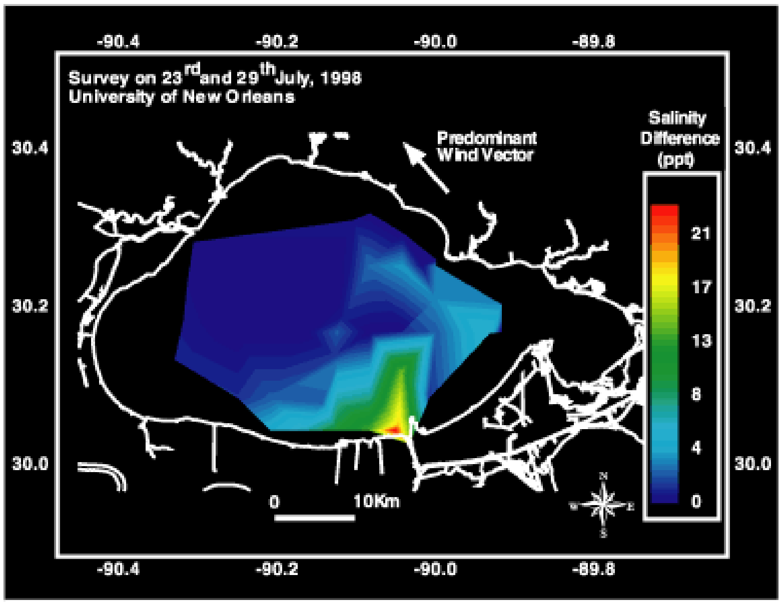


Figure 16. Contour map of salinity for Lake Pontchartrain, showing the plume of saltwater entering the Lake at Seabrook via the IHNC and its connection to the MRGO (McCorquodale et al., 2002).

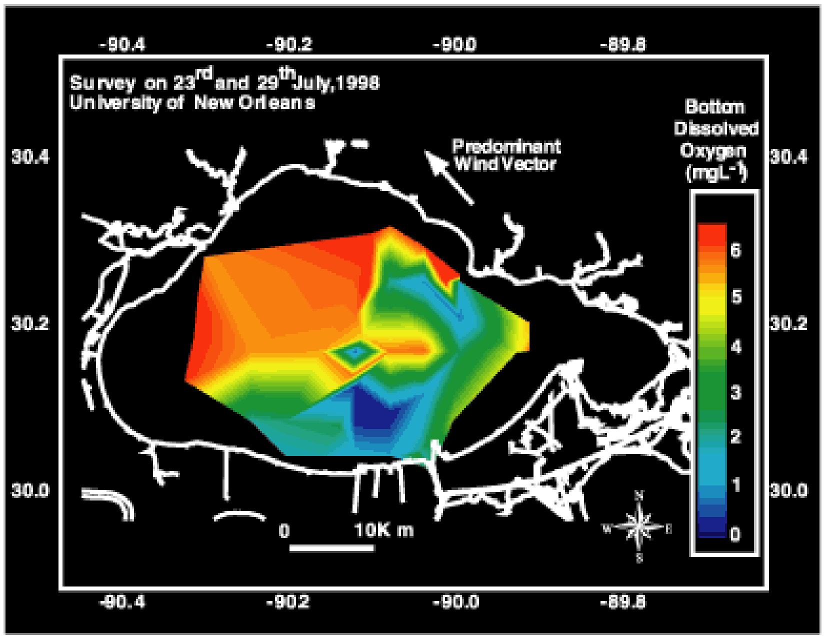


Figure 17. Contour map of bottom dissolved oxygen for Lake Pontchartrain, showing the hypoxic area created by stratification as a result of saltwater intrusion from the MRGO (McCorquodale et al., 2002)

The dead zone resulting from saltwater intrusion has had a negative impact on local biota, particularly *R. cuneata* clams which formerly dominated the Lake's benthos (Li et al., 2008). *Rangia* clams are capable of supporting a diverse fish assemblage. They are an important food source for many organisms, including *C. sapidus, M. undulatus*, Spot (*Leiostomus xanthurus),* and Black Drum *(Pogonias cromis).* They are also non-selective filter feeders capable of filtering the entire volume of Lake Pontchartrain in four days (Abadie and Poirrier, 2002). Through their feeding, they effectively turn phytoplankton and detritus into clam biomass, as well as remove harmful pathogens and bacteria such as fecal coliform from the water (Darnell, 1958; Abadie and Poirrier, 2002). As a result of shell dredging prior to 1990 in combination with conditions created in the Lake by the creation of the MRGO, the clam population fell to zero in the vicinity of the IHNC (Fig. 18).

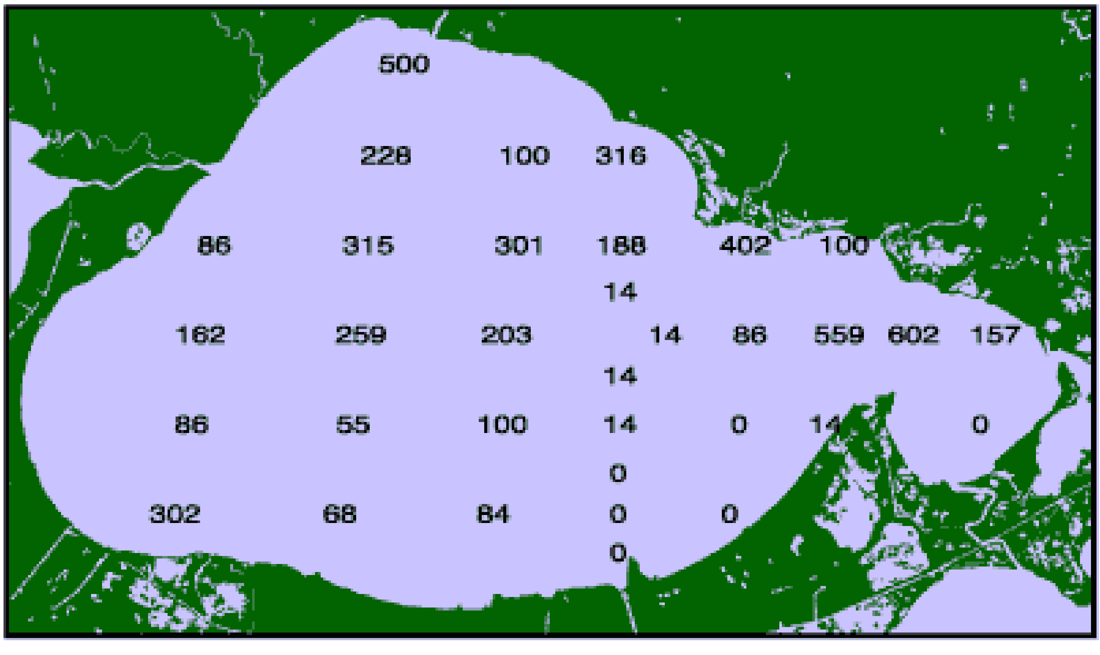


Figure 18. Map of Lake Pontchartrain showing the average density of large *Rangia cuneata* clams per square meter throughout the Lake bottom. The population of *R. cuneata* in the Lake near the entrance to the IHNC at Seabrook has been decimated) as a result of shell dredging and saltwater intrusion from the MRGO (Abadie and Poirrier, 2002).

For many years, local citizen and environmental groups, including the LPBF, fought for the closure of the MRGO and on June 5th, 2008 the USACE de-authorized the channel from the GIWW to the Gulf of Mexico. In July of 2009, the USACE completed a rock closure structure to the southeast of Bayou La Loutre in St. Bernard Parish (Fig.19). The closure was constructed using 357,648.51 metric tons of stone materials. It is 450 ft (137.16 m) wide at the bottom, with a 3.66 m crown and rises 2.44 m above the water (USACE, 2010; Fig. 20). Additionally, the USACE has since completed the IHNC-Lake Borgne Storm Surge Barrier, which provides a more solid barrier to the flow of water. The surge barrier runs from the southern bank of the MRGO (north of the rock closure), across the marsh area between the MRGO and the GIWW (known as the Golden Triangle), and then on to the northern bank of the GIWW (Fig. 21). There are gates in the GIWW which allow boat and shipping traffic, but can be closed in the event of a storm (Fig. 22)

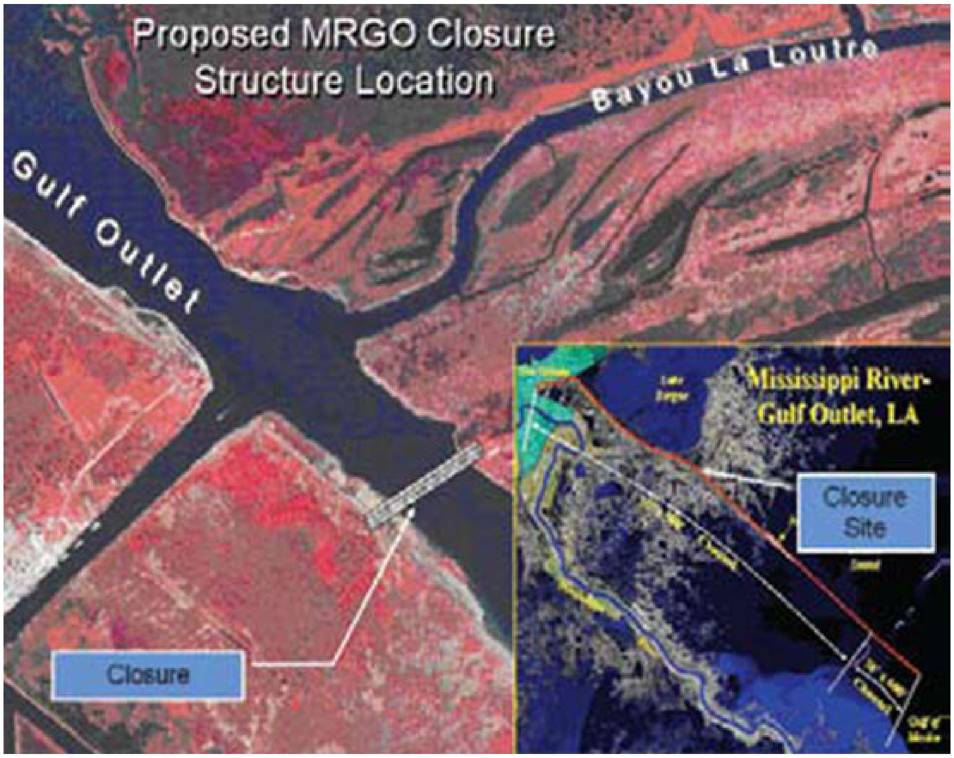


Figure 19. Map showing the location of the MRGO closure site, 15,000 ft southeast of Bayou La Loutre in St. Bernard Parish (Taken from the USACE website, www.mrgo.gov)

Figure 20. Image of the completed MRGO closure, August 4, 2009 (image from the USACE website www.mrgo.gov)

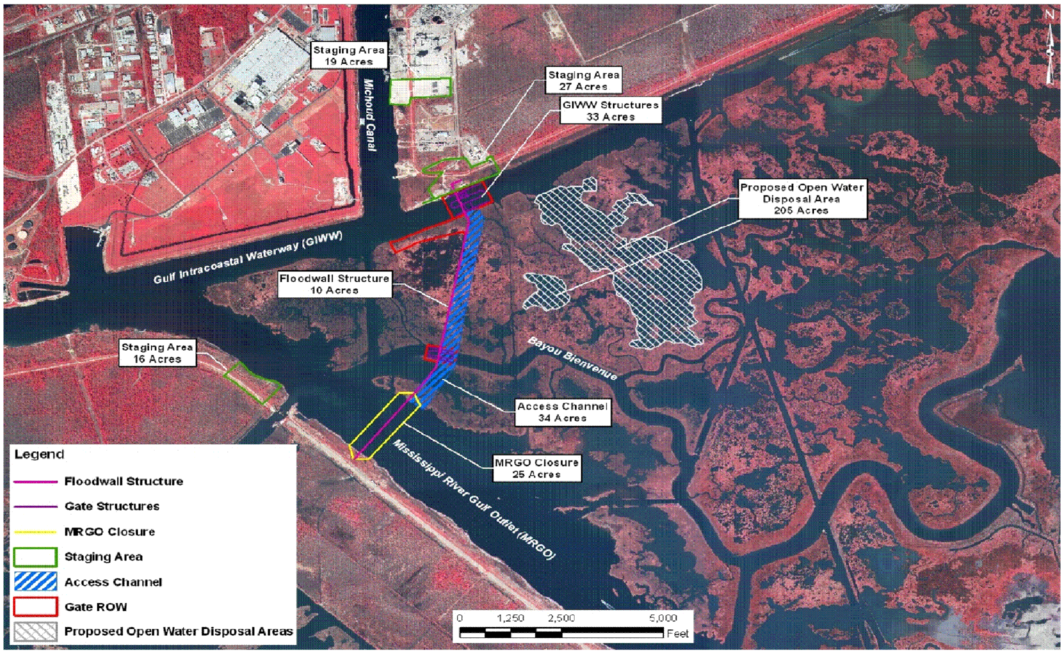


Figure 21. Location map of the IHNC-Lake Borgne Surge Barrier (image from Team New Orleans, Army Corps of Engineers http://www2.mvn.usace.army.mil)

Figure 22. Image of completed surge barrier, with the MRGO to the far left and the IHNC on the right. The flood gates are visible in the photograph, with the gates in the open position allowing for boat traffic to continue in the waterway during normal conditions. In the event of a storm, these gates can be closed. (Image from Team New Orleans, Army Corps of Engineers http://www2.mvn.usace.army.mil)

The MRGO closure represents a milestone for coastal restoration efforts in Louisiana. Models have indicated that the closure of the MRGO will result in a salinity decrease of 2-3 (+/- 3) in the Biloxi Marshes (Georgiou et al., 2009). However, the rock closure of the channel alone would not have been enough to begin to repair the decades-long assault on the surrounding ecosystem. Along with funds for the de-authorization of the MRGO, amounting to $13.62 million, money was allotted to various programs to ensure environmental restoration to the affected area. These projects include the Lake Borgne Wetlands Protection project, the MRGO at Shell Beach Wetlands Protection project, MRGO disposition of easements, and the MRGO Ecosystem Restoration Plan Feasibility Study. Remaining funds were slotted for wetlands creation and nourishment in the Golden Triangle and the Shell Beach vicinity, and also for shoreline protection along three different areas of Lake Borgne (Bayou Bienvenue vicinity, Bayou Dupre vicinity, and west of Shell Beach). All in all, MRGO operations maintenance appropriations amount to $75 million (USACE, 2010).

While restoration has been the main focus of the closure, another equally important concern that has received little attention is the potential for changes in the fish and invertebrate populations in these wetlands and associated water bodies. As previously mentioned, the estuary provides essential habitat for varying life stages of resident, estuarine-dependent and transient species. Lake Pontchartrain is home to over three-hundred species of fishes and invertebrates (Darnell, 1962). Estuarine-dependent fish and invertebrates that utilize the Lake Pontchartrain estuary for different stages of their lives include species such as *C. sapidus*, *S. ocellatus*, *L. xanthurus, M. undulatus* , *B. patronus* , White Shrimp (*Litopenaeus setiferus),* Brown Shrimp (*Farfantepenaeus aztecas)*, White Trout (*Cynoscion arenarius*) , and Striped Mullet (*Mugil cephalus*). Access to estuaries is necessary for the completion of their life cycle. Other organisms are transient, moving in and out of the Lake for feeding. These include such species as Crevalle Jack (*Caranx hippos*), Bull Sharks (*Carcharinus leucas*), and Bottlenose Dolphins (*Tursiops truncates*). Endangered Loggerhead Sea Turtles (*Caretta caretta*) and West Indian Manatees (*Trichechus manatus)* also move into the Lake at certain times of the year.

Commercial fisheries have historically been a primary component of the Louisiana economy and still are today. The livelihoods of many families in southern Louisiana depend on the vitality of its fisheries, as does the national demand for the seafood harvested from these waters. Louisiana's commercial fishing industry accounts for 20% of the nation's commercial landings and is estimated to provide 90,000 jobs in the state with an economic impact of $1.5 billion (Stedman and Hanson, 2000). Blue crabs from Lake Pontchartrain are shipped across the country for consumption. Over 70% of seafood harvested in the United States for commercial sale comes from coastal estuaries. Half of this comes from Louisiana's wetlands and is valued at $2.5-$4 billion annually (Yates, 1999).

The closure of the MRGO has the potential to affect not only the physical characteristics of Lake Pontchartrain, but also the living community such as commercial fisheries. The study of the changes in fish assemblages as a result of the MRGO closure and subsequent water quality changes are therefore as important as studies in coastal restoration. Changes that take place as salinity regimes shift must be tracked so that appropriate management decisions can be made. Changes in salinity can have effects on both the adult and juvenile fish populations, as well as on larval recruitment to the estuary. Larval organisms, of course, may also be affected by the physical closure of the MRGO. As such an important milestone in the restoration of coastal Louisiana, it is important to monitor the changes that take place as a result of the closure. There are many studies related to the restoration of wetlands following the closure of the MRGO, however there is a gap in the knowledge about the response of the fisheries in the area, in particular Lake Pontchartrain fisheries. This includes all life stages associated with the Lake. The University of New Orleans' Nekton Research Laboratory(NRL), along with government agencies such as the Louisiana Department of Fish and Wildlife (LDWF) have long-term data sets for adult and juvenile fishes along with data for crabs and shrimp, however there appears to be a lack of data on larval forms.

Therefore, my specific objectives in this study were to:

A) assess changes in the water quality, in particular salinity, of Lake Pontchartrain within four years following the MRGO closure;

B) determine any changes in the adult and juvenile fish assemblages in Lake Pontchartrain from one year prior to the MRGO closure until two years after; and

C) assess changes in larval fish assemblages in the tidal passes from six months before the MRGO closure until one year after.

Materials and Methods

Sampling for Adult and Juvenile Fishes

Collection Methods

For adult and juvenile fish surveys, the NRL employed three different gears types at six different sampling sites within Lake Pontchartrain. These sites represent the ecologically discernible regions of the estuary based on natural and anthropogenic factors (O'Connell et al., 2004; Fig. 23).

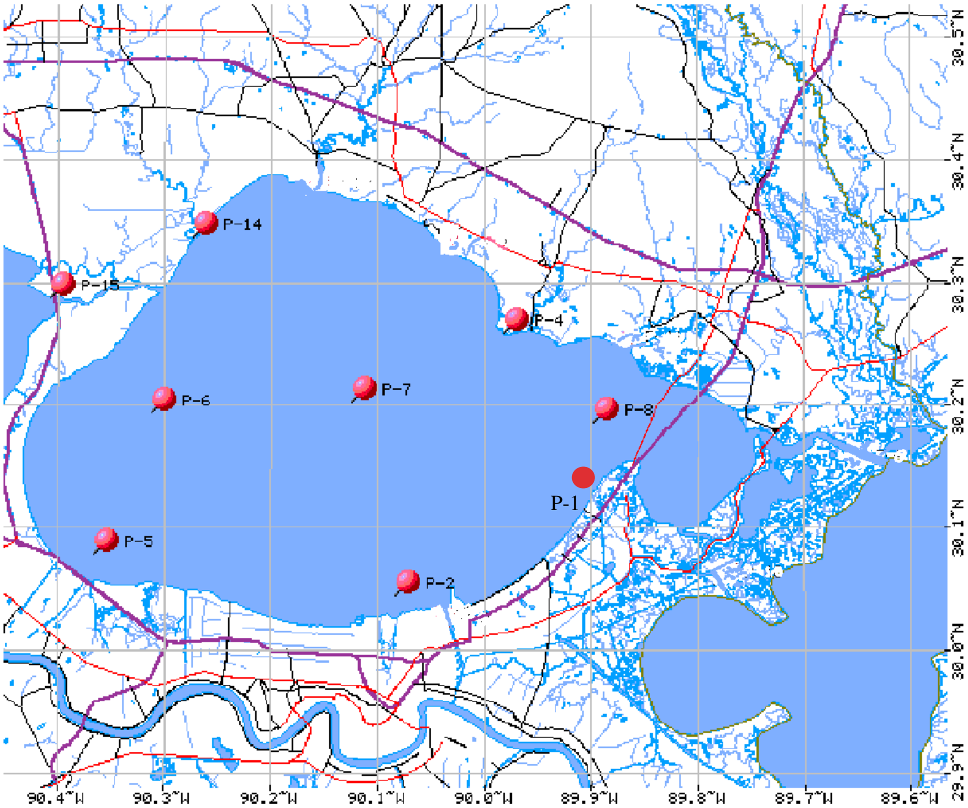


Figure 23. Location map of the University of New Orleans' Nekton Research Laboratory sampling sites for adult and juvenile fish and invertebrates. The sites correspond to the ecologically distinct regions of the Lake. For each site, three different gear types were used: gillnet, trawl, and beach seine; with the exception of P7 and P8 for which only gillnet and trawl sampling was conducted due to depth prohibiting seining (O'Connell et al., 2006)

For this study, two of these sites are used. Site P2 is located at Seabrook, which is the mouth of the IHNC and the closest point in Lake Pontchartrain to the MRGO. It is an important sampling site for assessing changes in water quality associated with the MRGO closure. Site P1 is located farther east at Irish Bayou. This represents the next closest site to the MRGO closure at which the NRL collects samples, making it suitable for comparison purposes in this study. The three gear types used for fish collection were trawls, gillnet, and beach seines. The different gear types are utilized to target different habitat types. The beach seine is used to collect nearshore species, trawls target demersal fishes in deeper water depths, and gill nets target pelagic species. Due to its nearshore utilization, the beach seine tends to target juveniles more than trawls and gillnets.

Ten-minute tows were performed using a 5 m otter trawl, a 100 m haul to the shore with a 15.2 x 1.8 m beach seine with a 1.8 m bag was performed, and the 228.6 x 2.4 m high gillnet was deployed using the “strike method”. For this, the gillnet was deployed and then three circles were made with the boat around the net as a means of driving the fish toward the net. Water quality data were taken for each sample collected and include measurements of salinity, turbidity, dissolved oxygen, specific conductivity, and temperature.

All samples were identified to the species level, measured, and counted. Larger fishes were processed on-board, while smaller ones were euthanized using sodium bi-carbonate and processed in the lab following approved UNO-IACUC procedure #09-016 (Appendix IV). Gillnet and beach seine sampling was conducted monthly, while trawl sampling was conducted monthly from November through February and twice monthly from March through October. This period corresponds with the most productive time period for *L. setiferus* and *F. aztecus*, and the NRL reported its counts to the LDWF to help in shrimping regulations.

Sampling for Larval Fishes

Collection Methods

Plankton tows were performed at three sites: Rigolets Pass and Chef Menteur Pass in Lake Pontchartrain, and in the IHNC at Seabrook. The Rigolets and Chef Menteur Passes are the two natural tidal inlets, while the Seabrook site was used to asses larval input to the Lake via the MRGO. Larval tows were performed during the strongest flowing tide period of the month. The tows were completed in triplicate, with three SeaGear "Bongo" nets (500 μ mesh size, attached to 1 m diameter hoops) towed simultaneously at the water surface for ten minutes across the width of the pass (perpendicular to the incoming tide) in order to cover as much of the pass as possible (Fig. 24). Using a Yellow Springs Instruments (YSI model 85 SCT-DO meter) meter, water quality data was collected for each site, including temperature (^{o}C), salinity, dissolved oxygen (mg/liter), and specific conductivity (mS). Additionally, turbidity was assessed by measuring water clarity with a secchi disk. Collected samples were preserved on-board with 10% Rose Bengal-dyed buffered formalin solution. The pink-colored dye is useful for identification of microscopic larval organisms, because it only stains living organisms. As the samples are often filled with various bits of organic matter, the dye can be extremely helpful. The samples were processed in the lab, where they were filtered utilizing a 250 μ sieve and then stored in a 70% ethanol solution. They were then sorted and identified taxonomically to the lowest possible level.

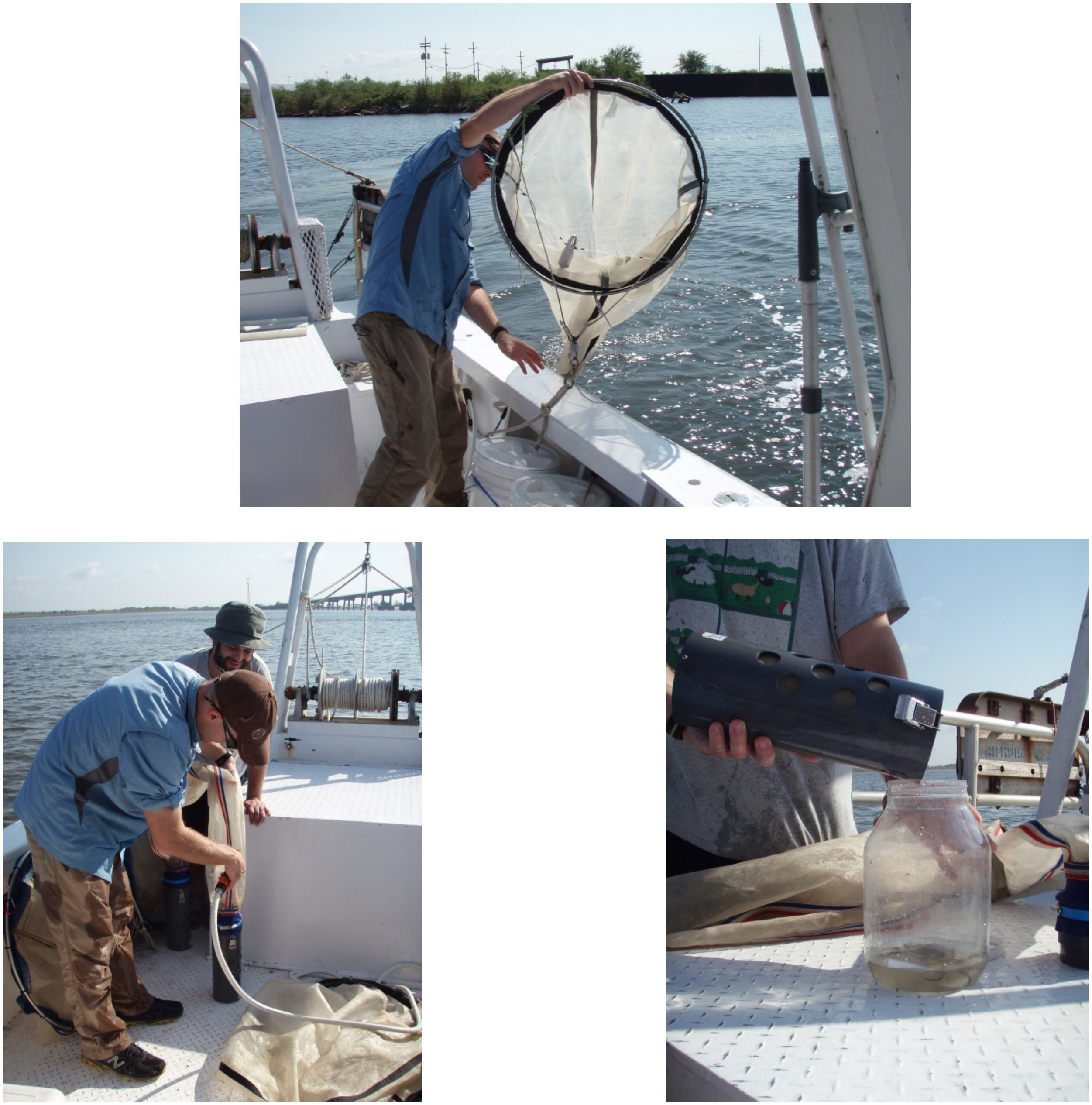


Figure 24. Images of collection methods for larvae: a) The SeaGear “Bongo” net used for capturing larval organisms in the tidal passes. Three nets were towed simultaneously at the water’s surface for ten minutes across the width of the pass and perpendicular to the incoming tide; b) organisms were washed down into the collection cylinder; c) samples were stored in jars containing a 10% Rose Bengal dye formalin-buffered solution to be transported to the lab for analysis.

Data Analyses

Long-term salinity data were provided by the LPBF from their weekly water quality monitoring sites around the Lake (Fig 30). For the purposes of this study, two of the LPBF sites were used: Pontchartrain Beach and Old Beach at the mouth of Bayou St. John just a short distance to the west. These are the closest sites to the NRL's Seabrook site, and therefore are beneficial for assessing changes in salinity in response to the MRGO closure. Unfortunately, while the NRL data is useful for examining trends in salinity, the data do not cover a sufficient span of time to make any real conclusions. Therefore the LPBF data, taken from January 2001 until June 2013, was used for statistical analysis. For this, regression analyses were conducted to determine if salinity changed significantly over time at the two sites. All analyses of salinity were conducted using SPSS version 19.

All biotic data were analyzed using the Plymouth Routines in Multivariate Ecological Research (PRIMER) version 6 statistical software package. This program is commonly used to assess changes in ecological communities. A benefit to using the program is that sample data does not have to follow a normal distribution. To analyze the adult fish data, non-metric multidimensional scaling (MDS) plots were constructed to depict the relationships of the assemblages based on a Bray-Curtis similarity matrix. The data were square-root transformed to take some weight off of the more dominant species thus allowing for visible interpretation of assemblage similarity or dissimilarity. Assemblages that are composed of more similar species appear closer together than those which have more variation. Some outliers were removed to allow for greater visual interpretation. Following MDS plot construction, a two-way crossed analysis of similarity (ANOSIM; $p= 0.05$) was then applied to test for significant differences among assemblages. When performing the ANOSIM, the factors used were site (P1 and P2) and pre-/post-closure. The pre-closure sampling dates ran from July 2008 to August 2009, and post-closure sampling was from September 2009 to June 2011. The data for adult sampling included collections with all three gear types (beach seine, trawl, and gillnet). Similarity percentage analysis (SIMPER) was then performed to give average similarity and dissimilarity values, whereby it was possible to assess which species contributed most to assemblage difference. BIO-ENV was then used for determining the relationships between abiotic (water quality) measurements and biotic (fish assemblage) changes. For this analysis, a Euclidean distance similarity matrix was constructed (no transformation), and factors used were again site and pre-/post-closure. The abiotic data was compared to the adult biotic similarity matrix, producing correlation values between the biotic and abiotic data. Finally, dispersion analysis was performed for the adult data to determine variability within assemblages from before and after the MRGO closure. Increased fish assemblage variability has been used as an identifiable symptom of perturbed situations, therefore comparisons of relative multivariate dispersion indices (RMD) for assemblages representing different sites can be used to determine which regions and habitats appeared most affected by the closure of the MRGO (Warwick and Clarke, 1993).

Calculating relative multivariate dispersion indices begins with the construction of a triangular non-metric multidimensional scaling (MDS) similarity matrix (Clarke and Warwick, 2001). The values in this matrix are measures of Bray-Curtis similarity for all pair-wise comparisons of assemblage data. For example, if the fish assemblage collected at Time 1 from Site A is very similar to that collected at Time 1 from Site B, the Bray-Curtis similarity would be relatively large. A pair of fish assemblages that were dissimilar would have a lower Bray-Curtis similarity index and so on. All pair-wise comparisons are included in the MDS similarity matrix and are the basis for calculating a relative multivariate dispersion index for each sampling site. From the matrix, only those intra-site similarities (i.e., changes over the pre- and post-closure years at each site in the present study) are averaged to calculate relative dispersion for the fish assemblage of a given site. Greater values indicate greater dispersion or increased fish assemblage instability (Clarke and Warwick, 2001).

Larval data were analyzed in the same fashion with comparisons made among sites (Rigolets Pass, Chef Menteur Pass, and Seabrook) and pre-/post-closure. For the larval sampling, pre-closure data collection was from February 2009 to July 2009, and post-closure sampling ran from September 20009 until July 2010. Data was again square-root transformed as there were a couple of dominant species. The same analyses as performed for the adult data were then conducted (ANOSIM, SIMPER, BIO-ENV). ANOSIM was used to assess changes among the three ichthyoplankton collection sites and then SIMPER analysis showed the dominant species at each site. BIO-ENV was used to find any correlations between abiotic and biotic data. Dispersion analysis was then also performed with the larval fish data to assess variation within each assemblage. Finally, data were compiled for all three tidal passes to determine the relative contributions of each pass to the total influx of larvae into the Lake both before and after the MRGO closure.

Results

Changes in water quality: pre-closure vs. post-closure

During the collection period for this study, water quality readings were taken each time sampling was conducted for both adult and larval sampling. Data taken include water temperature (^{o}C), salinity, dissolved oxygen (mg/liter), and specific conductivity (mS), and secchi depth (m). These data are useful for making comparisons between the sites before the closure of the MRGO and after the closure.

Salinity data were of particular interest for the purposes of the current study. From the data collected, there was an evident trend of decreasing salinity in the areas sampled. Data from the adult collections suggested that both sites (P1/Irish Bayou and P2/Seabrook) experienced decreases in salinity. Scatter plots of the data also revealed that some seasonal variation was apparent, with increases in the late summer and early fall, and decreases in the winter and early spring. These fluctuations coincided with the rainy and dry seasons that are prevalent in the regions. Despite the variation, however, the trend over the course of the study was that of decreasing salinity in surface waters (Fig. 25, Fig. 26). The adult data were collected over three years, from July 2008 until June 2011. The rock wall closure in the MRGO was completed in July of 2009, therefore the salinity data from the adult sampling represent one year prior to the closure and nearly two years after. As there were three different types of sampling conducted at each site, the salinity values recorded during the three sampling procedures were averaged to give a mean salinity determination for the site.

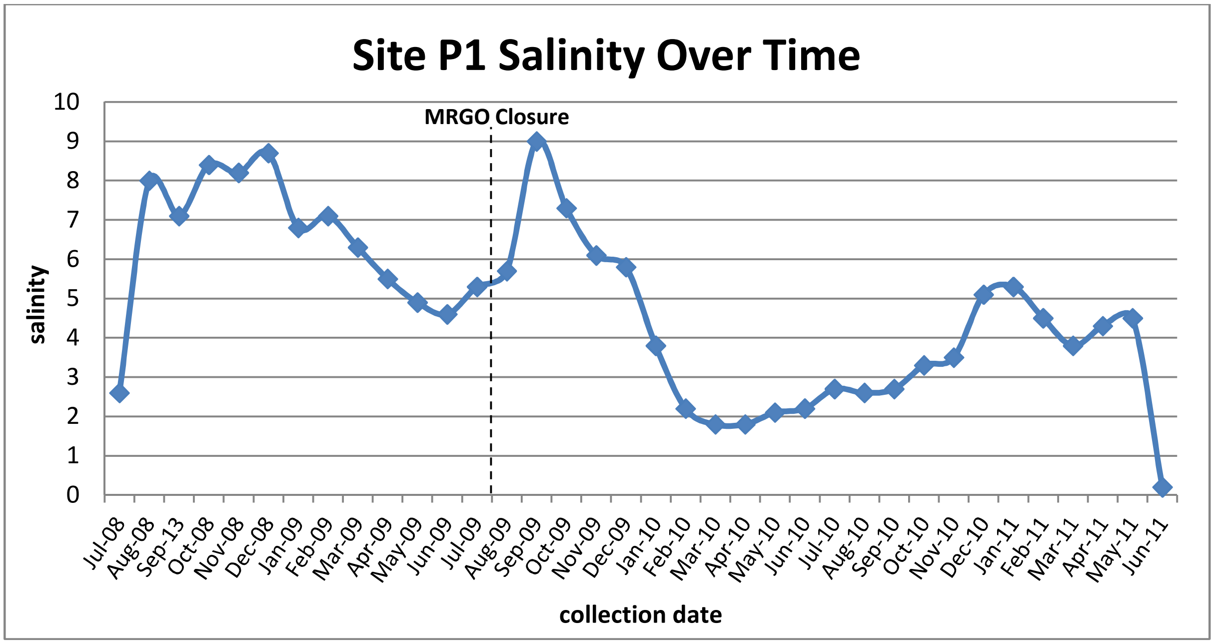


Figure 25. Scatter plot of salinity data (averaged for the day) taken from surface waters at P1 during the adult fish collections beginning in July 2008 and ending in June 2011. This corresponds to a year before the closure of the MRGO and two years after.

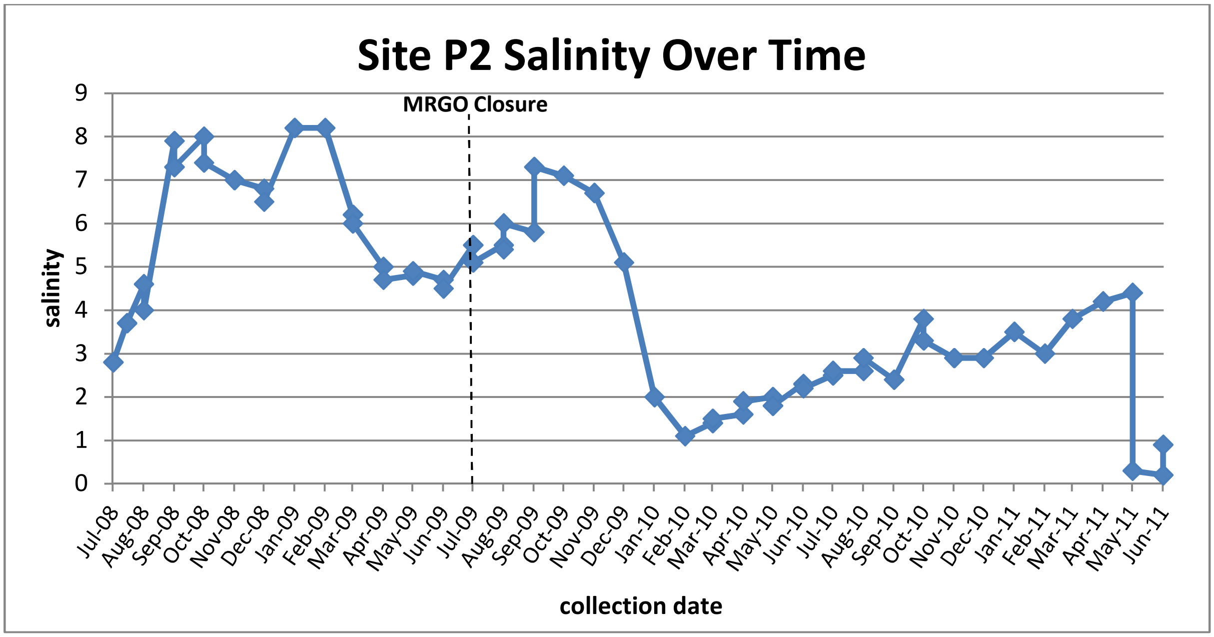


Figure 26. Scatter plot of salinity data (averaged for the day) taken in surface waters at site P2 during the period of the study, from July 2008 until June 2011. This corresponds to a year before the closure of the MRGO in July of 2009 until two years after the closure.

Water quality data taken during the larval collections in the tidal passes are also presented below. The time period for these data was from February 2009 until August 2010. This was roughly six months before the closure and a year after. As with the adult salinity data, there were seasonal fluctuations visible in the scatter plots shown. From assessing the data, though, there was a trend of decreasing salinity in both Seabrook and Chef Menteur Pass, while there was a slight upward trend in Rigolets Pass (Fig. 27, Fig. 28, Fig. 29). The sharpest decrease was at Seabrook, the site which should show the biggest changes in response to the MRGO closure. Where there was previously a large saltwater plume moving up the MRGO from the Gulf of Mexico, the flow is now greatly decreased. An important difference between sampling at Seabrook for adult versus larval collection was that sampling was conducted outside of the canal for adult data, but inside the canal for larval data. Therefore, there were discrepancies between the salinity data for “P2” for adult collection and “Seabrook” for larval data. Both sites, however, did show steep declines in salinity over time.

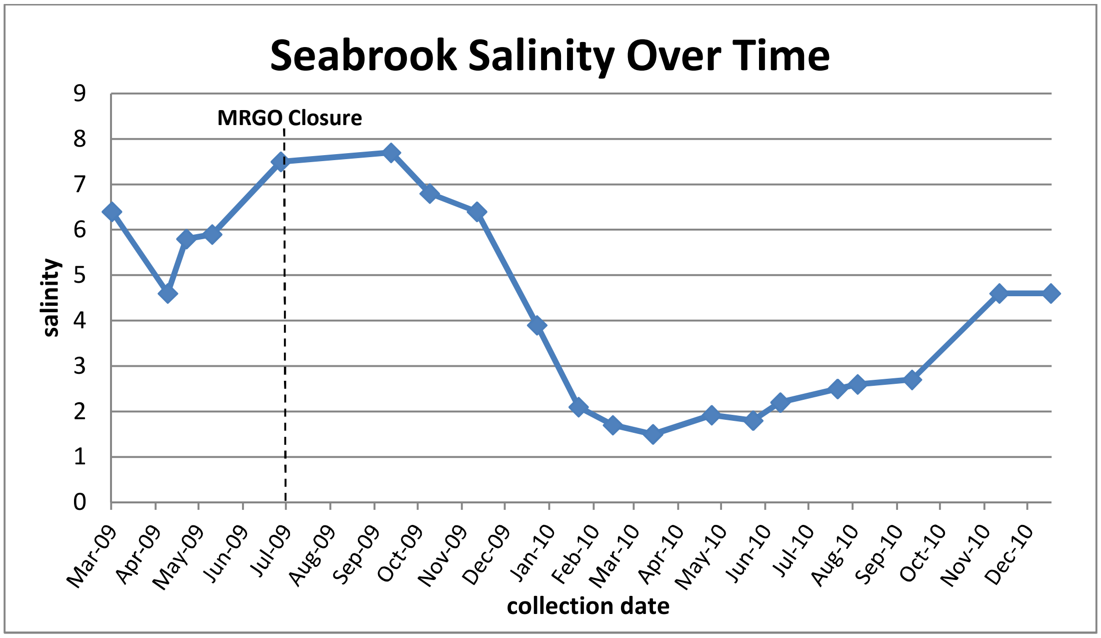


Figure 27. Scatter plot of the salinity data (averaged for the day) collected in surface waters at Seabrook within the IHNC shows a sharp downward trend from the beginning of the larval sampling period in March 2009 to the end in December 2010.

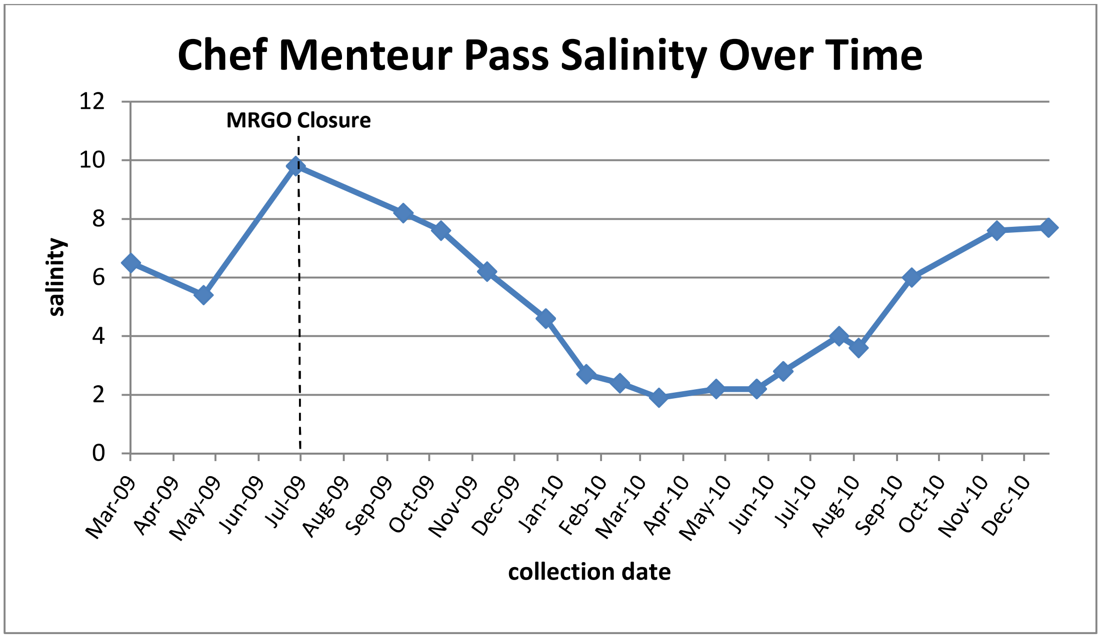


Figure 28. Scatter plot of salinity data (averaged for the day) taken in surface waters in Chef Menteur Pass during the larval collection sampling from March 2009 to December 2010. The trendline shows the overall decrease in salinity in the tidal pass from six months prior to the MRGO closure to a year and a half following the closure.

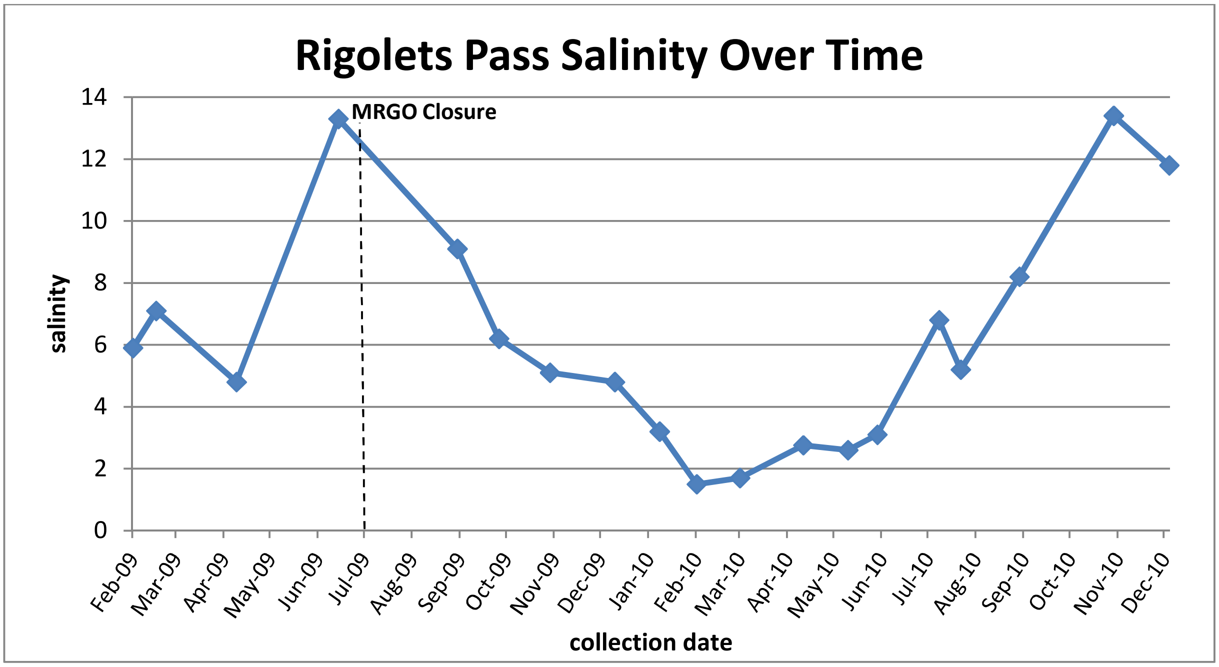


Figure 29. Scatter plot of salinity data (averaged for the day) taken in surface waters in Rigolets Pass during the larval sampling from March 2009 until December 2010. The trendline shows a slight increase in the salinity in Rigolets Pass during the collection period.

Despite showing evidence of a downward shift in salinity patterns during the collection period, three years is not a sufficient amount of time to make any real conclusions regarding apparent changes. Therefore, as mentioned above, water quality data taken on a weekly basis by the Lake Pontchartrain Basin Foundation was used for a more thorough investigation of salinity shifts. The data presented here from Pontchartrain Beach and Old Beach span a period of 13.5 years, from January 2001 until June 2013 (Fig. 30). From these data, regression analyses were conducted for salinity changes from before the MRGO closure and after the MRGO closure. The results of the analyses showed a significant decline in salinity at Pontchartrain Beach ($R^2 = 0.071_{(1, 653)}$, $p < 0.001$) and also a significant decline in salinity at Old Beach ($R^2 = 0.076_{(1, 625)}$, $p < 0.001$). The data are also presented below, and show the evident downward trend in salinity at both sites (Fig. 31, Fig. 32), even while showing short-term variation in response to seasonal and environmental factors, as indicated on the graphs. These include such things as hurricanes, spillway openings, and normal variation with seasonal precipitation and temperature patterns.

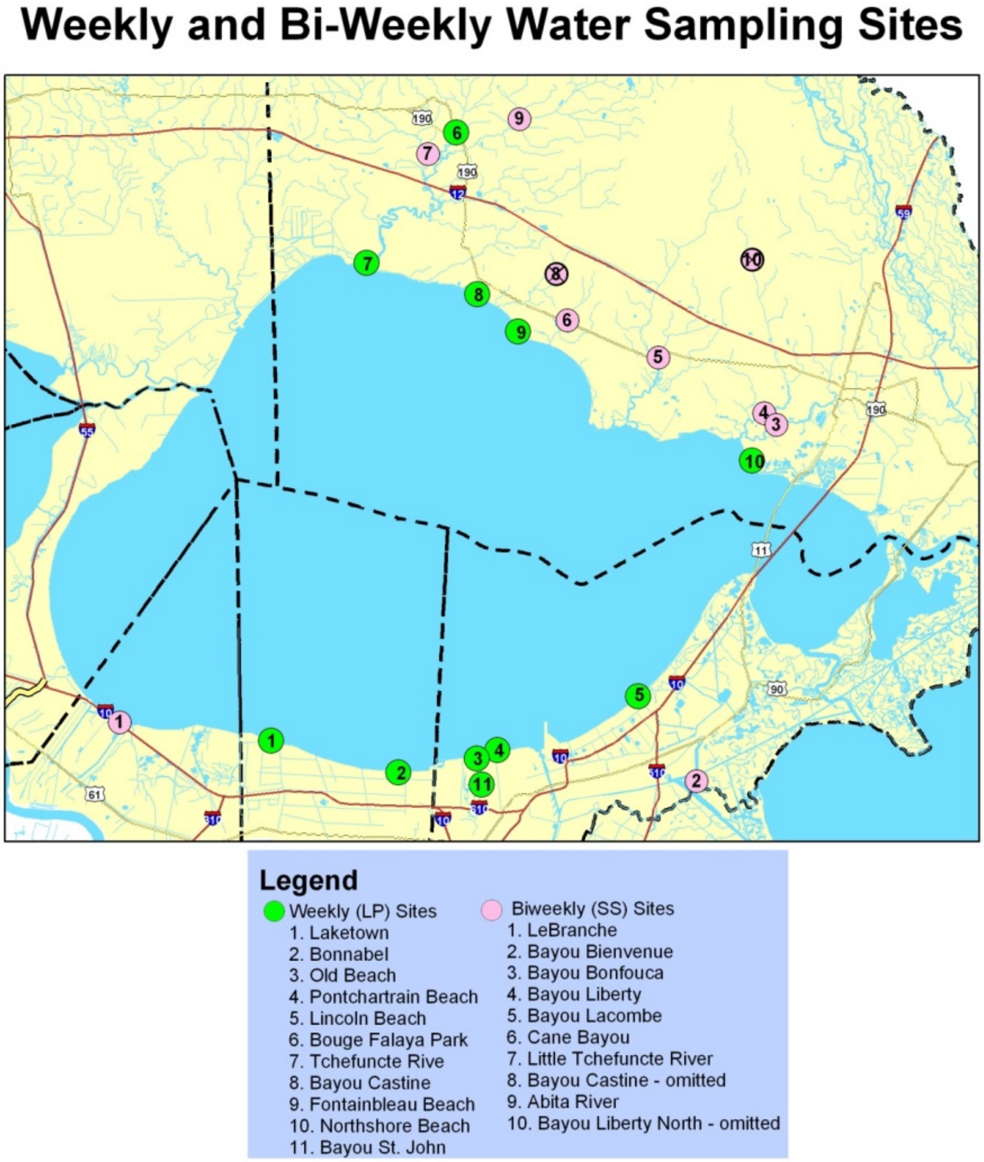


Figure 30. Map of the sites around Lake Pontchartrain that the Lake Pontchartrain Basin Foundation conducts water quality monitoring. Salinity data provided by the LPBF from Site 4 (Pontchartrain Beach) and Site 3 (Old Beach) were utilized for this study. These are the closest sites to Seabrook. (Image courtesy of the Lake Pontchartrain Basin Foundation)

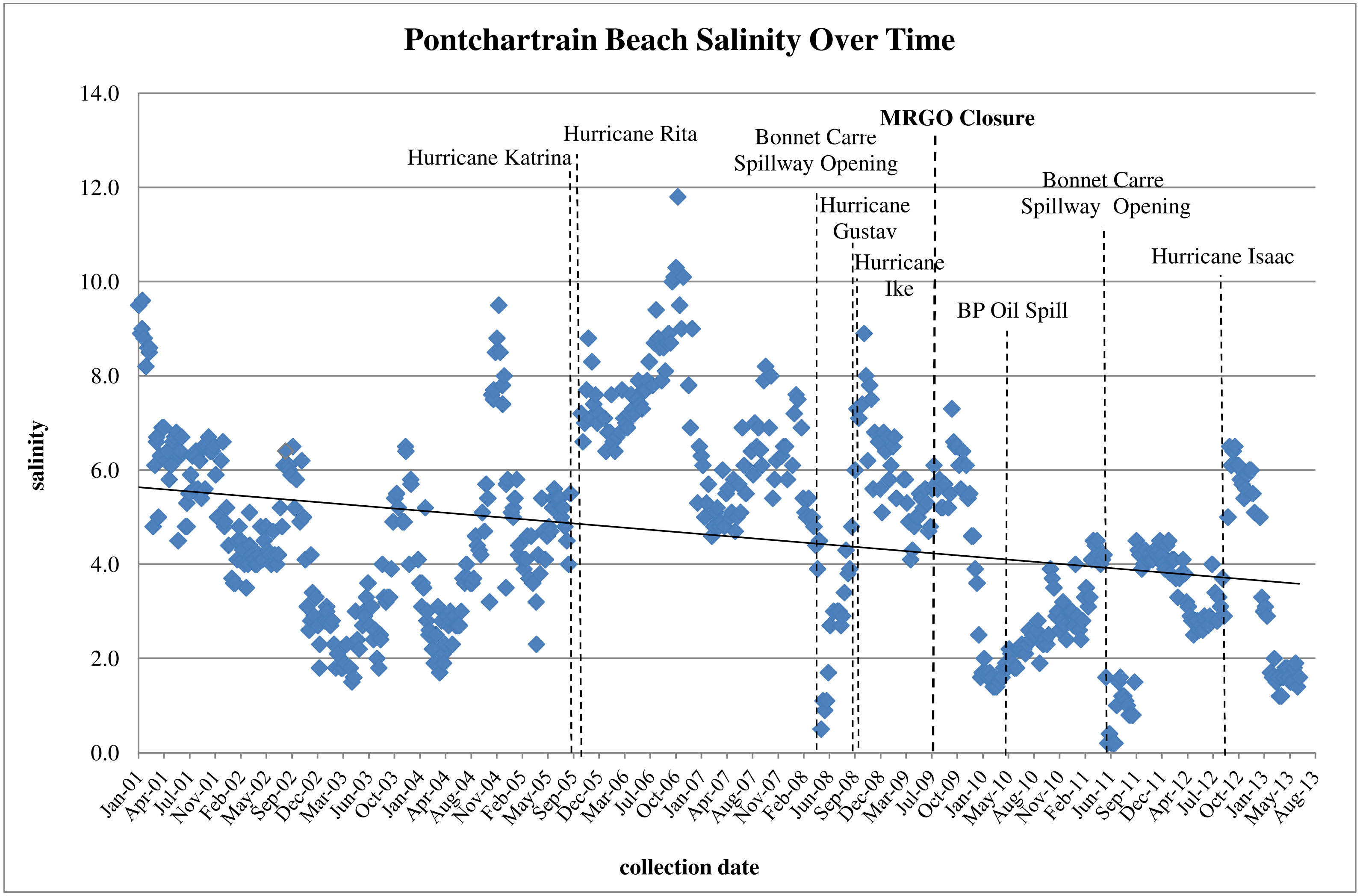


Figure 31. This chart shows salinity data provided by the LPBF taken at Pontchartrain Beach from January 2001 to June 2013. Important environmental events are indicated on the graph. This long-term data set shows evidence of decreasing salinity in the Lake.

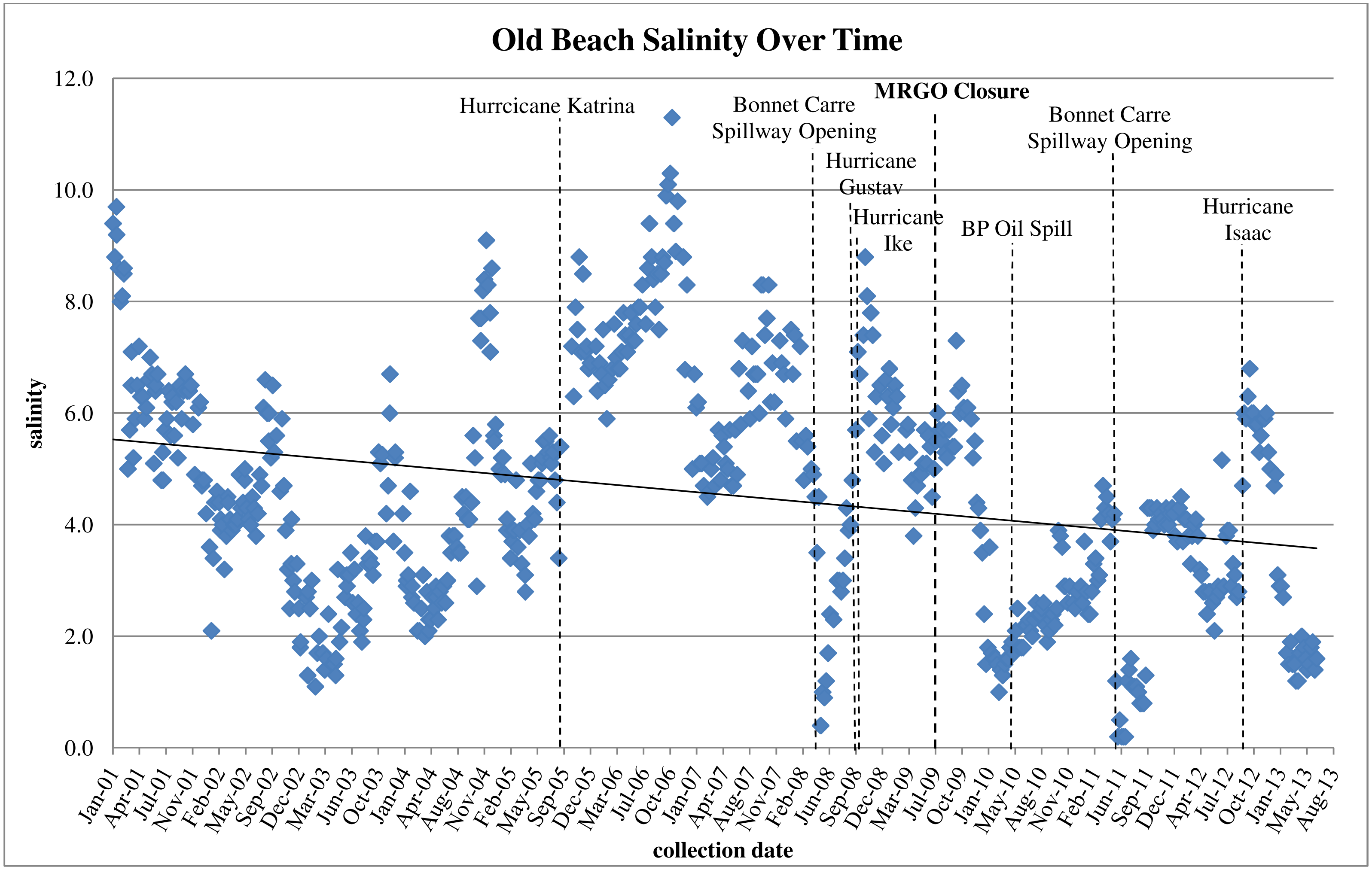


Figure 32. Salinity data showing evidence of decline over the 13.5 year monitoring period. The data were collected by the LPBF from January 2001 to June 2013 at Old Beach at the mouth of Bayou St. John. Major environmental events are indicated on the graph.

Adult and Juvenile Fish Collection

For this study, data were used from trawl, gillnet, and beach seine collections from July 2008 until June 2011. These methods of collecting fisheries data target different depths within the water column, and thus are beneficial in surveying fishes of varying sizes and in different habitat types. The different species of fish and their abundances were summarized for the two different adult collection sites, P1 and P2, and analyzed in PRIMER for any changes occurring as a result of the MRGO closure (See Appendix I for PRIMER results). The MDS plots generated showed fish assemblages at sites P1 and P2 across the sampling years (2008-2011) corresponding to pre- and post-closure (Fig. 33). Pre-closure data were from July 2008 until August 2009, and post-closure data were from September 2009 until June 2011. P1 appeared less variable than P2, as the samples were more clustered together than those of P2. Analysis of similarity, however, showed no statistically significant differences in the adult and juvenile fish assemblages between for pre- and post-closure groups (ANOSIM, R= -0.044, p = 0.88). There were also no significant differences found between site groups (ANOSIM, R= -0.0002, p= 0.5).

Results of the SIMPER analysis showed 30.07% average similarity between species at P1 versus 11.64% average similarity between groups at P2, indicating that P2 was more variable than P1. The results of the analysis showed the most dominant species at P1, in order of decreasing average abundance as presented below (Table 2). They include the Bay Anchovy (Anchoa *mitchilli),* Inland Silverside *(Menidia beryllina), B. patronus, L. xanthurus,* Pinfish *(Lagodon rhomboides),* Rainwater Killifish *(Lucania parva), M. cephalus, M. undulatus*, *and* Gulf Killifish *(Fundulus grandis).* The overall make-up of the fish assemblage at P1 is also presented below, with the abundances of *A. mitchilli* and *B. patronus* depicted separately due to extremely high numbers impeding visual interpretation of the other species present (Table 6, Fig.

34, Fig. 35). The data collected at P2 in decreasing order are shown below (Table 3). They indicate that the most dominant species were *A. mitchilli, B. patronus, M. beryllina, M. cephalus, M. undulatus, L. xanthurus*, Clown Goby *(Microgobius gulosus),* and Gafftopsail Catfish *(Bagre marinus)*. The most abundant species found by far at P2 was *A. mitchilli* both before the MRGO closure and after (Fig. 36). All other species present at P2 both before and after the closure are presented for comparison below (Table 7, Fig. 37). Only by excluding *A. mitchilli* from this chart could the abundances of other species present be depicted. SIMPER analysis found that the average dissimilarity between groups P1 and P2 was 88.44%. The data showed that while there were several similar species found between the two sites, their abundances varied a great deal between sites (Table 4). The top five species that contributed most to the average dissimilarity between sites were *A. mitchilli* (23.04%), followed by *M. beryllina* (16.38%), *B. patronus* (7.04%), *A. hepsetus* (5.59%), *and M. undulatus* (4.39%). The BIO-ENV analysis of the two sites showed very weak correlations between the fish assemblages at the two sites and the water quality data (Table 5). From this, the best parameter that described P1 and P2 was secchi depth, however the Spearman Correlation value was low (0.084).

As results of the ANOSIM, SIMPER, and BIO-ENV were not very informative, dispersion analysis was also conducted in PRIMER. The results of the analyses showed low dispersion at P1 both before and after the MRGO closure (pre-closure RMD = 0.359, post-closure RMD = 0.489), with a slight increase post-closure. The data showed fairly low dispersion at P2 (although a bit higher than P1) before the closure (RMD = 0.83), but much greater dispersion after the closure (RMD = 1.135).

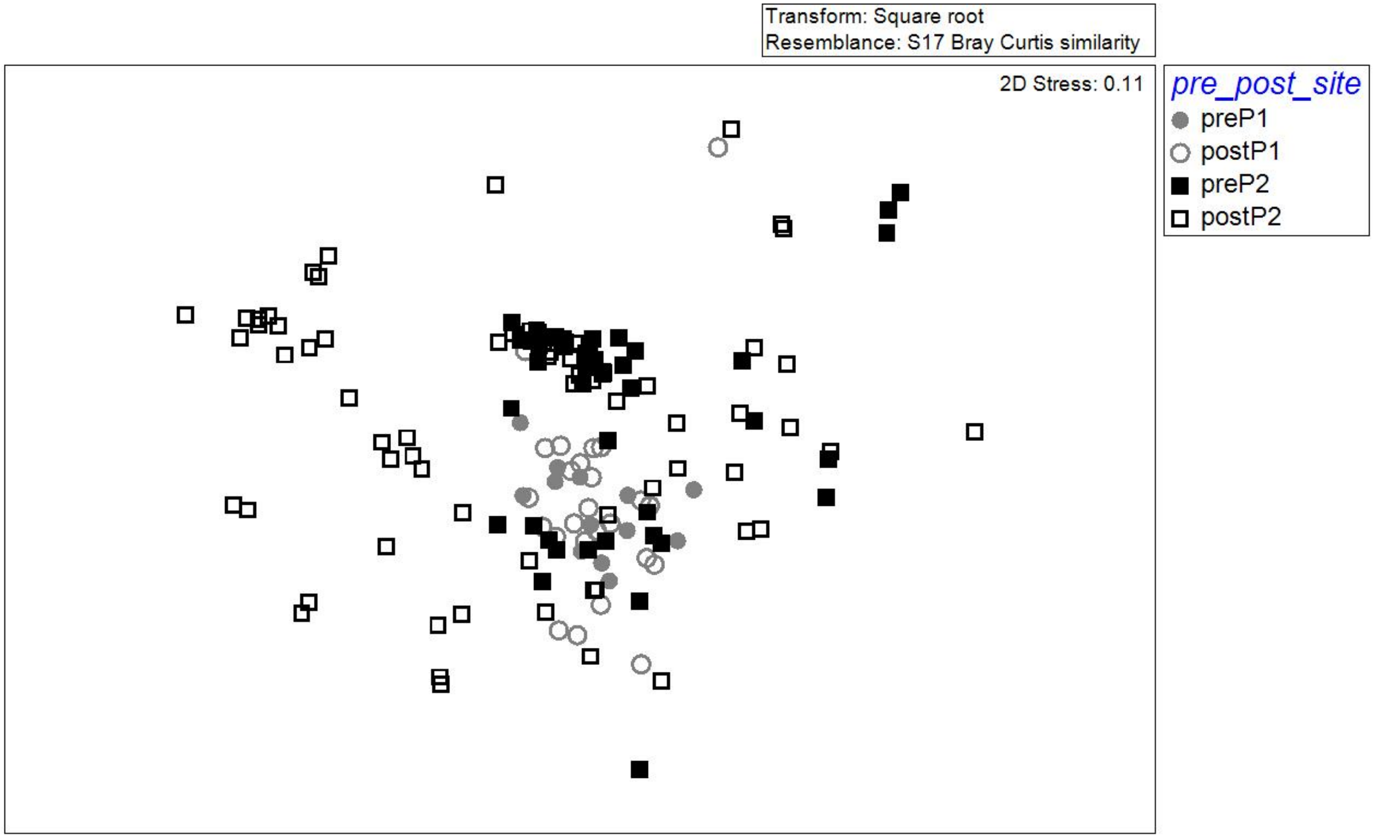


Figure 33. Multidimensional scaling plot (MDS) of adult and juvenile fish assemblages collected at sites P1 and P2 from July 2008 to August 2009 (pre-closure) and September 2009 to June 2011 (post-closure). The circles represent data for site P1, with closed gray circles corresponding to pre-closure P1 samples and the open circles corresponding to post-closure P1 samples. The squares represent data from site P2, with closed black squares corresponding to pre-closure P2 samples and open squares corresponding to post-closure P2 samples. Four outliers were removed for visual purposes. Here, it appears that P1 is less variable than P2 both before and after the closure of the MRGO.

Table 2. Similarity Percentage (SIMPER) analysis for Group P1 shows the most dominant species of the fish assemblage at that site. Results indicate that Bay Anchovy (*Anchoa mitchilli*) was the most dominant species based on its average abundance.

Group P1 - Average similarity = 30.07	
Species	Average Abundance
Anchoa mitchilli	62.79
Menidia beryllina	48.63
Brevoortia patronus	28.29
Leiostomus xanthurus	3.05
Lagodon rhomboides	2.68
Lucania parva	2.74
Mugil cephalus	2.13
Micropogonias undulatus	1.29
Fundulus grandis	1.11

Table 3. Similarity Percentage (SIMPER) analysis for Group P2 gave the most dominant species of the fish assemblage at that site. Bay Anchovy (*Anchoa mitchilli*) was by far the most dominant species based on its abundance.

Group P2 - Average similarity = 11.64	
Species	Average Abundance
Anchoa mitchilli	269.36
Brevoortia patronus	120.28
Anchoa hepsetus	82.91
Micropogonias undulatus	7.76
Menidia beryllina	6.86
Microgobius gulosus	4.13
Leiostomus xanthurus	3.98
Bagre marinus	0.49

Table 4. Similarity Percentages (SIMPER) for fish assemblages at sites P1 and P2 collected before and after the MRGO closure. The species' average abundances are given for each site, and the final column of the table shows the average dissimilarity each species contributed to the overall dissimilarity between assemblages.

Groups P1 and P2 - Average dissimilarity = 88.44			
Species	Group P1 Average Abundance	Group P2 Average Abundance	% Contribution
Anchoa mitchilli	62.79	269.36	23.04
Menidia beryllina	48.63	6.86	16.38
Brevoortia patronus	28.29	120.28	7.04
Anchoa hepsetus	0.71	82.91	5.59
Micropogonias undulatus	1.29	7076	4.39
Mugil cephalus	2.13	2.65	3.69
Leiostomus xanthurus	3.05	3.98	3.6
Lucania parva	2.74	0.03	2.9
Lagodon rhomboides	2.68	0.23	2.56
Bairdiella chrysoura	2.68	1.65	2.22
Mugil curema	7.37	1.53	2.21
Membras martinica	0.61	6.43	2.02
Fundulus grandis	1.11	0.26	1.91
Cynoscion nebulosus	1.03	0.41	1.91
Stronylura marina	0.82	1.13	1.91
Syngnathus scovelli	1.84	0.02	1.8
Microgobius gulosus	0	4.13	1.78
Elops saurus	0.5	1.34	1.64
Cyprinodon variegatus	6.97	0.11	1.49
Sciaenops ocellatus	0.5	0.55	1.2
Cynoscion arenarius	0.87	0.21	1.18

Table 5. Results of BIO-ENV analysis for the adult data collected at sites P1 and P2 indicate that secchi contributed most to changes in fish assemblages associated with the MRGO closure. All correlations were weak, however. The five water quality variables measured were water temperature, secchi depth, salinity, specific conductivity, and dissolved oxygen.

Number of Variables	Spearman Correlation Value	Selections
1	0.084	secchi
4	0.077	water temperature, secchi, salinity, specific conductivity
3	0.077	water temperature, salinity, specific conductivity
3	0.077	water temperature, secchi, specific conductivity
5	0.076	water temperature, secchi, salinity, specific conductivity, dissolved oxygen
2	0.076	water temperature, specific conductivity
4	0.076	water temperature, salinity, specific conductivity, dissolved oxygen
4	0.076	water temperature, secchi, specific conductivity, dissolved oxygen
3	0.075	water temperature, specific conductivity, dissolved oxygen
3	0.071	water temperature, secchi, salinity

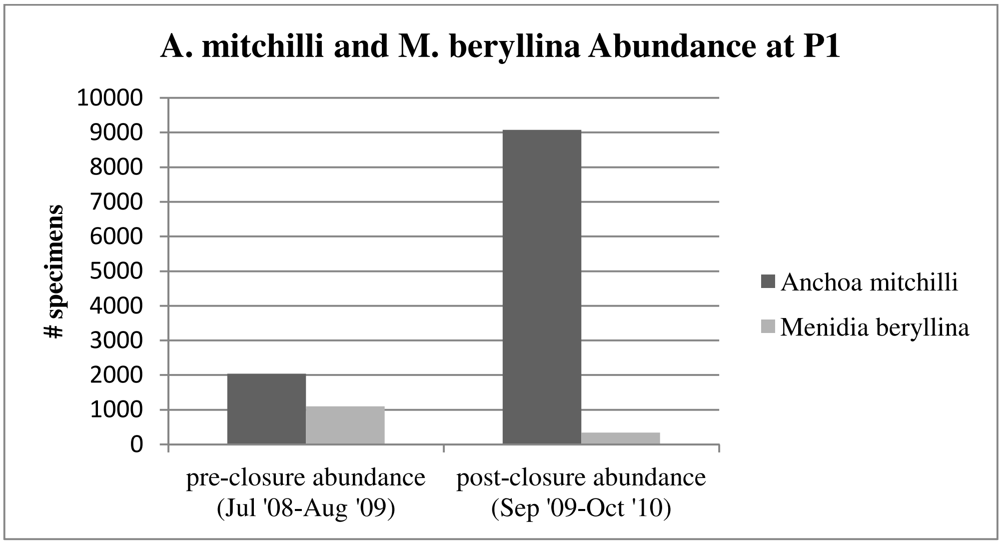


Figure 34. The chart shows the total abundance of *A. mitchilli* and *M. beryllina* at site P1. For comparison, only fourteen months of post-closure data were used to compare to the fourteen months of pre-closure data that was collected. These species were found in much higher abundance than other species at the site.

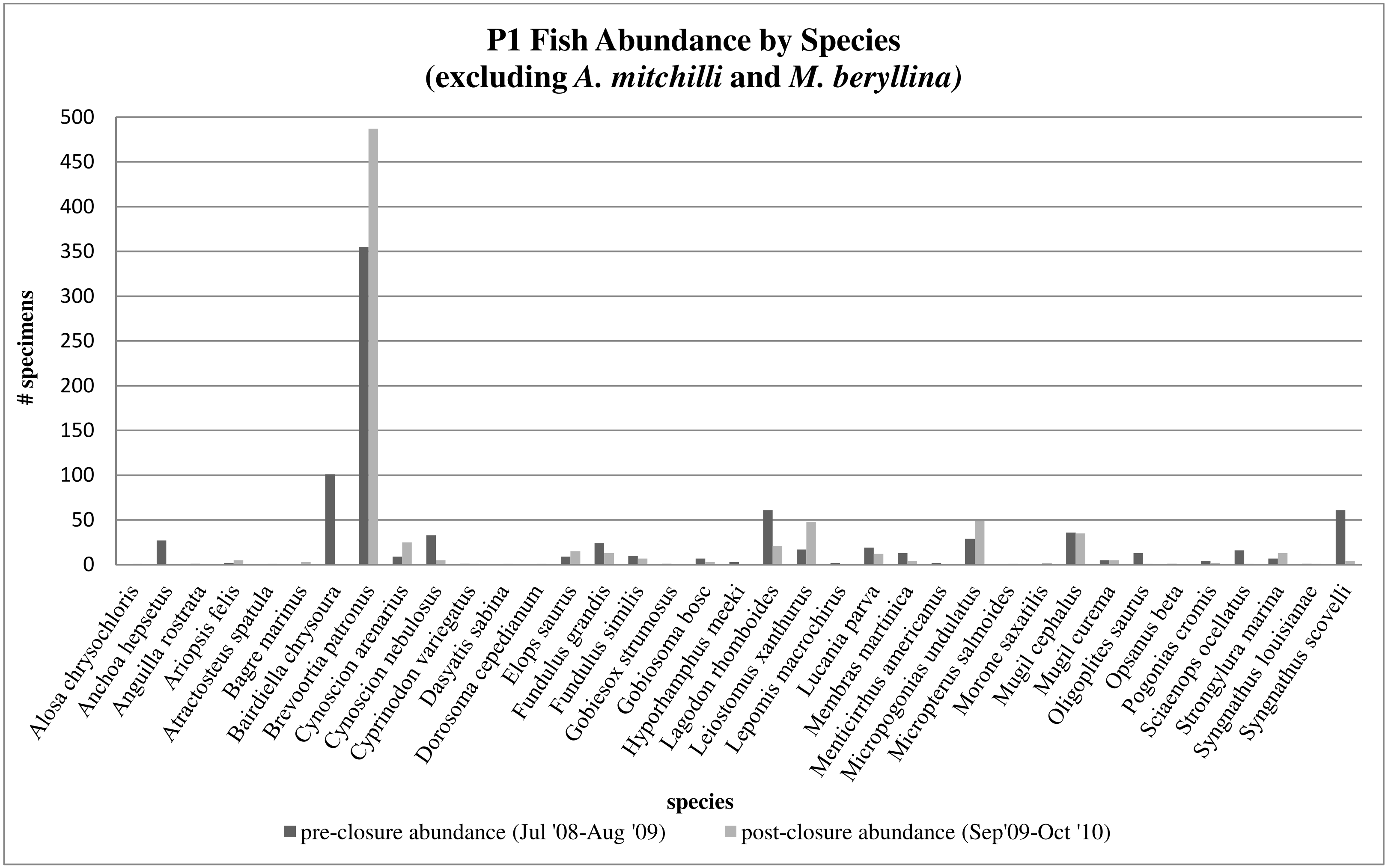


Figure 35. The chart shows the abundance of each species found at site P1 from the first fourteen months following the closure were used to see differences from the fourteen months of sampling that were completed before the closure (excluding *A. mitchilli* and *M. beryllina* due to very high abundances).

Table 6. The species composition of site P1 is shown in the table with total abundance from the fourteen month collection period prior to the MRGO closure and fourteen months post-closure.

species	pre-closure abundance (Jul '08-Aug '09)	post-closure abundance (Sep' 09-Oct '10)
Alosa chrysochloris	0	1
Anchoa hepsetus	27	0
Anchoa mitchilli	2044	9077
Anguilla rostrata	1	0
Ariopsis felis	2	5
Atractosteus spatula	0	1
Bagre marinus	0	3
Bairdiella chrysoura	101	0
Brevoortia patronus	355	487
Cynoscion arenarius	9	25
Cynoscion nebulosus	33	5
Cyprinodon variegatus	1	1
Dasyatis sabina	0	1
Dorosoma cepedianum	0	1
Elops saurus	9	15
Fundulus grandis	24	13
Fundulus similis	10	7
Gobiesox strumosus	1	0
Gobiosoma bosc	7	3
Hyporhamphus meeki	3	0
Lagodon rhomboides	61	21
Leiostomus xanthurus	17	48
Lepomis macrochirus	2	0
Lucania parva	19	12
Membras martinica	13	4
Menidia beryllina	1095	340
Menticirrhus americanus	2	0
Micropogonias undulatus	29	49
Micropterus salmoides	0	1
Morone saxatilis	0	2
Mugil cephalus	36	35
Mugil curema	5	5
Oligoplites saurus	13	1
Opsanus beta	1	0
Pogonias cromis	4	2
Sciaenops ocellatus	16	1
Strongylura marina	7	13
Syngnathus louisianae	1	1
Syngnathus scovelli	61	4

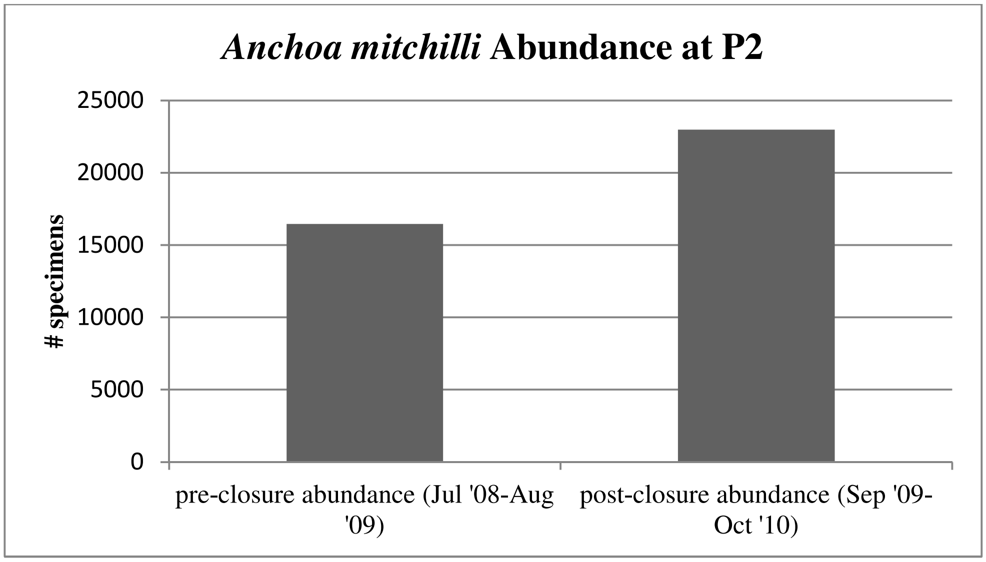


Figure 36. The chart shows the comparison between pre- and post-closure data at P2 for *A. mitchilli,* which the most abundant species.

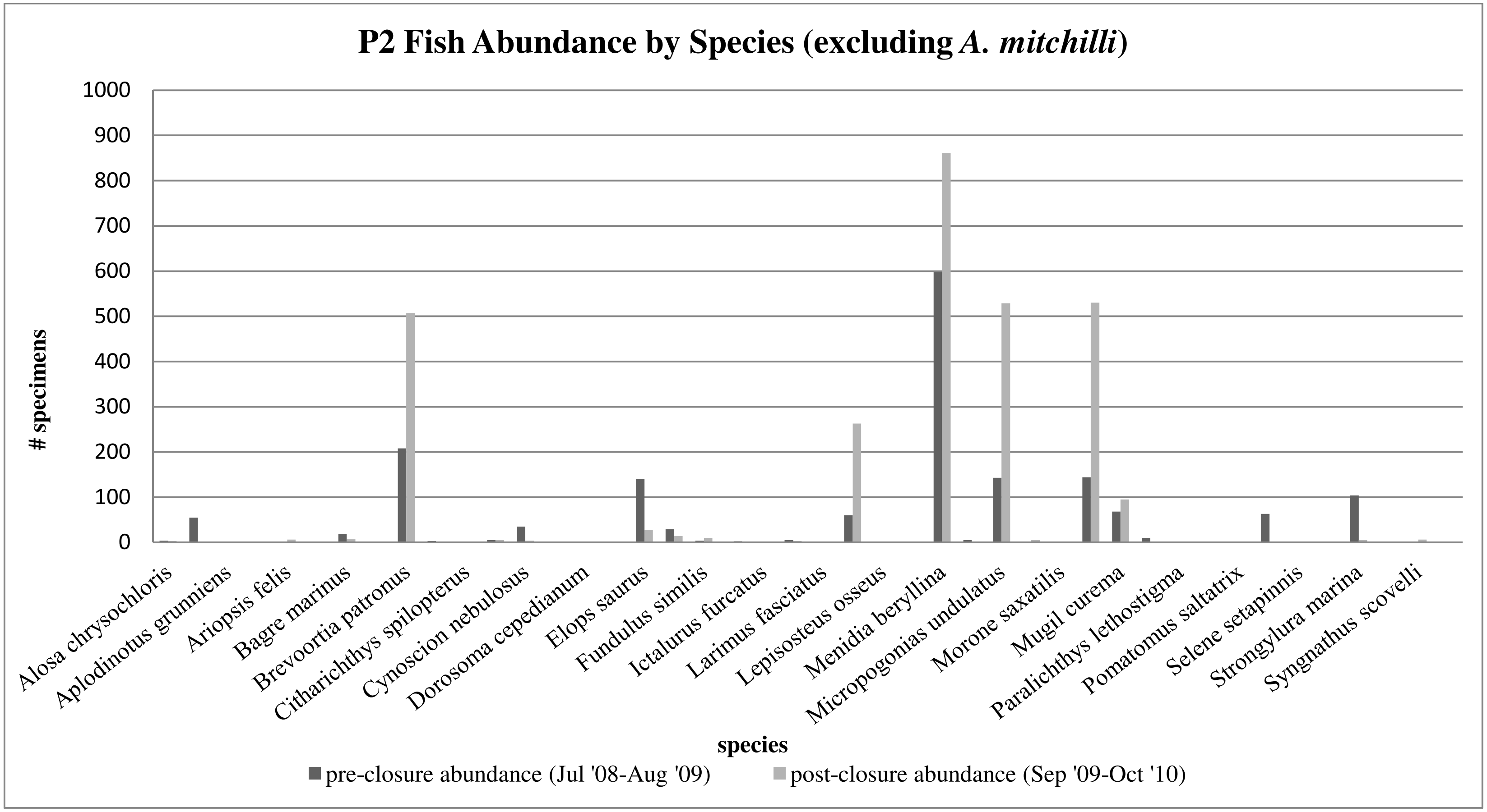


Figure 37. Species composition of adult and juvenile fishes at Seabrook (P2) from data collected before and after the closure of the MRGO. For comparison purposes only fourteen month of data were used from post-closure collection data to correspond with the fourteen months of data collected prior to the closure. Bay Anchovy (*A. mitchilli*) is excluded from the chart due to its extremely high abundance.

Table 7. Species composition of adult and juvenile fish at site P2 with abundances given for pre-closure and post-closure.

species	pre-closure abundance (Jul '08-Aug '09)	post-closure abundance (Sep '09-Oct '10)
Alosa chrysochloris	4	3
Anchoa hepsetus	55	1
Aplodinotus grunniens	1	0
Archosargus probatocephalus	0	1
Ariopsis felis	1	6
Atractosteus spatula	0	1
Bagre marinus	19	7
Bairdiella chrysoura	1	1
Brevoortia patronus	208	507
Caranx hippos	3	0
Citharichthys spilopterus	1	0
Cynoscion arenarius	5	5
Cynoscion nebulosus	35	4
Dasyatis sabina	0	2
Dorosoma cepedianum	2	0
Dorosoma petenense	2	0
Elops saurus	140	28
Fundulus grandis	29	14
Fundulus similis	4	10
Gobiosoma bosc	0	3
Ictalurus furcatus	1	1
Lagodon rhomboides	5	3
Larimus fasciatus	1	0
Leiostomus xanthurus	60	263
Lepisosteus osseus	1	0
Lucania parva	1	1
Menidia beryllina	598	861
Menticirrhus americanus	5	0
Micropogonias undulatus	143	529
Micropterus salmoides	1	5
Morone saxatilis	0	2
Mugil cephalus	144	530
Mugil curema	68	95
Oligoplites saurus	10	2
Paralichthys lethostigma	2	1
Pogonias cromis	1	0
Pomatomus saltatrix	1	0
Sciaenops ocellatus	63	0
Selene setapinnis	2	0
Sphoeroides parvus	1	0
Strongylura marina	104	5
Symphurus plagiusa	1	0
Syngnathus scovelli	2	6
Trinectes maculatus	0	2

Larval Fish Collection

The larval fish data were analyzed in the same fashion as the adult fish data in PRIMER (See Appendix II for PRIMER results; Appendix III for photographs of larval fish). For this, first an MDS plot was generated to visualize any differences between the three tidal passes (Chef Menteur Pass, Rigolets Pass, and in the IHNC at Seabrook). From this, it appeared that Seabrook was more variable than the other two sites (Fig. 38). Next, analysis of similarity was performed to look for any significant differences among the passes from pre-closure sampling to post-closure sampling. As with the adult data, there were no significant differences among site groups (ANOSIM, R = 0.007, p = 0.354). There were also no significant differences among pre-closure and post-closure groups (ANOSIM, R = -0.057, p = .918). Similarity percentage (SIMPER) analysis showed an average similarity of 14.24% among species in Rigolets Pass. Chef Pass had an average similarity of 13.83% among species, and Seabrook had an average similarity of 13.17% among species. The most dominant species in each pass were determined (Tables 8, 9, 10). In all three passes, the top three dominant species were *A. mitchilli, B. patronus*, and *M. beryllina*. Their average abundance varied among passes. The average dissimilarity in species composition between groups was then calculated. The average dissimilarity between larval fish assemblages in Rigolets Pass and Chef Menteur Pass was 86.2%. The average dissimilarity between assemblages in Rigolets Pass and Seabrook was 87.87%, and 85.95% between Chef Menteur Pass and Seabrook. The average abundances of the species contributing most to differences among the fish assemblages in the three tidal passes and their percent contributions are summarized below (Tables 11, 12, 13). Following SIMPER analysis, a BIO-ENV analysis was conducted. As was expected based on the lack of significance found among pre-closure and post-closure larval fish assemblages in the three passes, the BIO-

ENV showed weak correlations between water quality and fish assemblages (Table 14). The correlations were a bit stronger than for the adult fish data, however they still did not present any strong evidence of changes in water quality affecting fish assemblages over time. Given the lack of findings from the ANOSIM, SIMPER, and BIO-ENV, dispersion analysis was then conducted to look for any patterns of variation in the fish assemblages at each sampling site. The results of the analysis showed that the pre-closure Seabrook site was the most stable with the least variable larval fish assemblage (RMD = 0.712), followed by Rigolets Pass (RMD = 0.858) and then Chef Pass (RMD = 0.874). All of the pre-closure larval fish assemblages were less variable than the post-closure assemblages. Seabrook showed the most change, going from the least variable to one of the most variable following the MRGO closure (RMD = 1.063). Rigolets Pass had the same dispersion value as Seabrook following the closure (RMD = 1.063). Chef Menteur Pass had the least variable post-closure fish assemblage (RMD = 0.997).

To reveal possible species compositional differences among passes, pre- and post-closure data were examined and compared at each pass (Figs.39-43). The relative contributions of each tidal pass to the total amount of larval fish found during the pre- and post-closure collection periods were determined. The pre-closure Seabrook contributed 46.6% of larval fish versus 33.3% post-closure. Rigolets contributed 34.1% pre-closure versus 36.5% post-closure, and Chef 19.2% pre-closure versus 30% post-closure (Figs. 44 and 45) . The post-closure months used for these calculations did not include the entire sampling period following the closure, but rather for the months corresponding to those collected during the pre-closure sampling period.

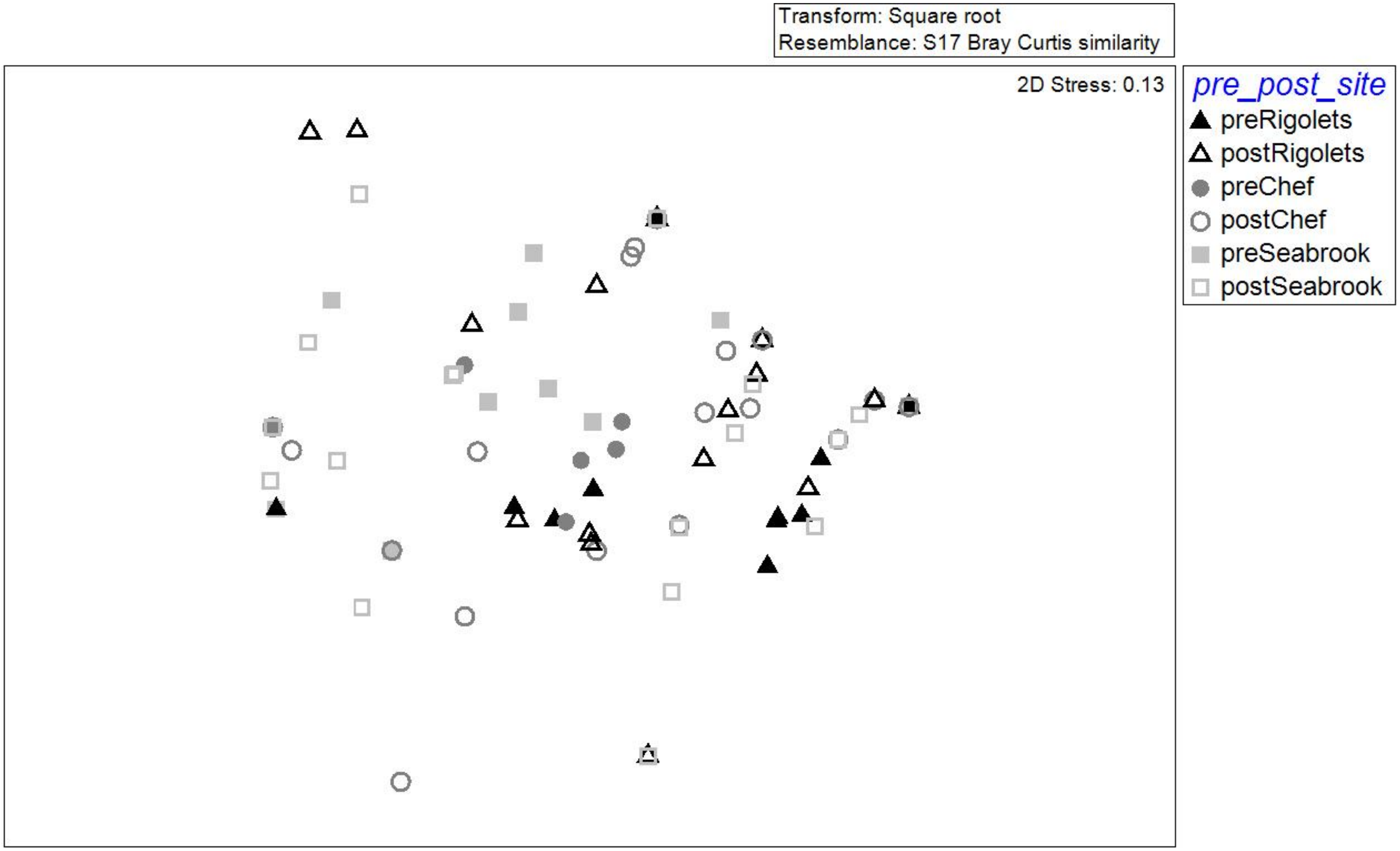


Figure 38. Multidimensional scaling plot (MDS) plot of the larval fish assemblage data collected from February 2009 to July 2010 in each of the three tidal passes: Chef Menteur, Rigolets, and in the IHNC at Seabrook. Closed, black triangles represent pre-closure Rigolets Pass samples, while open triangles represent post-closure Rigolets Pass samples. Closed gray circles represent pre-closure Chef Menteur Pass samples and open gray circles represent post-closure Chef Menteur Pass samples. Closed gray squares correspond to pre-closure Seabrook samples, while open gray squares correspond to post-closure Seabrook samples.

Table 8. The average similarity of the fish assemblage in Rigolets Pass was 14.24%. The average abundances of the most dominant larval fish species in the pass are given below.

Group Rigolets - Average Similarity = 14.24	
Species	Average Abundance
Brevoortia patronus	10.62
Anchoa mitchilli	10.48
Menidia beryllina	7.55
Unknown A	2.62
Syngnathus scovelli	0.31
Prionotus tribulus	0.14
Gobiesox strumosus	1.9
Caranx hippos	0.17

Table 9. The average similarity of the fish assemblage in Chef Menteur Pass was 13.83%. The average abundances of the most dominant larval fish species in the pass are given below.

Group Chef - Average Similarity = 13.83	
Species	Average Abundance
Brevoortia patronus	8.41
Anchoa mitchilli	5.93
Menidia beryllina	5.97
Unknown A	3.69
Syngnathus scovelli	0.28
Gobiesox strumosus	0.24
Elops saurus	0.07

Table 10. The average similarity of the fish assemblage in the IHNC at Seabrook was 13.17%. The average abundances of the most dominant larval fish species in the pass are given below.

Group Seabrook - Average Similarity - 13.17	
Species	Average Abundance
Menidia beryllina	2.48
Brevoortia patronus	9.1
Anchoa mitchilli	9.21
Prionotus tribulus	1.45
Syngnathus scovelli	0.31
Unknown A	0.59
Gobiesox strumosus	0.1
Strongylura marina	0.07

Table 11. The top species contributing to the dissimilarity between fish assemblages in Rigolets Pass and Chef Menteur Pass are given below, along with their average abundance and percent contribution to differences in assemblages.

Groups Rigolets & Chef - Average Dissimilarity = 86.20			
Species	Group Rigolets Average Abundance	Group Chef Average Abundance	% Contribution
Brevoortia patronus	10.62	8.41	37.69
Anchoa mitchilli	10.48	5.93	23.52
Menidia beryllina	7.55	5.97	17.23
Unknown A	2.62	3.69	9.45
Caranx hippos	0.17	0.03	3.54
Prionitus tribulus	0.14	0.03	2.81
Syngnathus scovelli	0.31	0.28	2.35
Gobiesox strumosus	1.9	0.24	2.05

Table 12. The top species contributing to the dissimilarity between fish assemblages in Rigolets Pass and Seabrook are given below, along with their average abundance and percent contribution to differences in assemblages.

Groups Rigolets & Seabrook - Average Dissimilarity = 87.87			
Species	Group Rigolets Average Abundance	Group Seabrook Average Abundance	% Contribution
Brevoortia patronus	10.62	9.1	36.07
Anchoa mitchilli	10.48	9.21	20.89
Menidia beryllina	7.55	2.48	19.78
Prionitus tribulus	0.14	1.45	8.71
Unknown A	2.62	0.59	4.04
Syngnathus scovelli	0.31	0.31	3.47
Caranx hippos	0.17	0	2.61
Gobiesox strumosus	1.9	0.1	2.36

Table 13. The top species contributing to the dissimilarity between fish assemblages in Chef Menteur Pass and Seabrook are given below, along with their average abundance and percent contribution to differences in assemblages.

Groups Chef & Seabrook - Average Dissimilarity = 85.95			
Species	Group Chef Average Abundance	Group Seabrook Average Abundance	% Contribution
Brevoortia patronus	8.41	9.1	27.99
Menidia beryllina	5.97	2.48	22.77
Anchoa mitchilli	5.93	9.21	22.08
Unknown A	3.69	0.59	10.11
Prionitus tribulus	0.03	1.45	8.18
Syngnathus scovelli	0.28	0.31	3.79
Gobiesox strumosus	0.24	0.1	1.46
Caranx hippos	0.03	0	0.87

Table 14. Results of BIO-ENV analysis for the larval data collected in the three passes indicate that salinity and water temperature contributed most to changes in fish assemblages associated with the MRGO closure. All correlations were weak, however. The four water quality variables measured were water temperature, salinity, specific conductivity, and dissolved oxygen. Secchi depth data was not consistent and so could not be used for analysis.

Number of Variables	Spearman Correlation Value	Selections
2	0.361	specific conductivity, water temperature
3	0.358	specific conductivity, salinity, water temperature
2	0.352	salinity, water temperature
1	0.334	water temperature
4	0.312	dissolved oxygen, specific conductivity, salinity, water temperature
3	0.312	dissolved oxygen, specific conductivity, water temperature
3	0.286	dissolved oxygen, salinity, water temperature
2	0.266	dissolved oxygen, water temperature
2	0.227	dissolved oxygen, specific conductivity
3	0.218	dissolved oxygen, specific conductivity, salinity

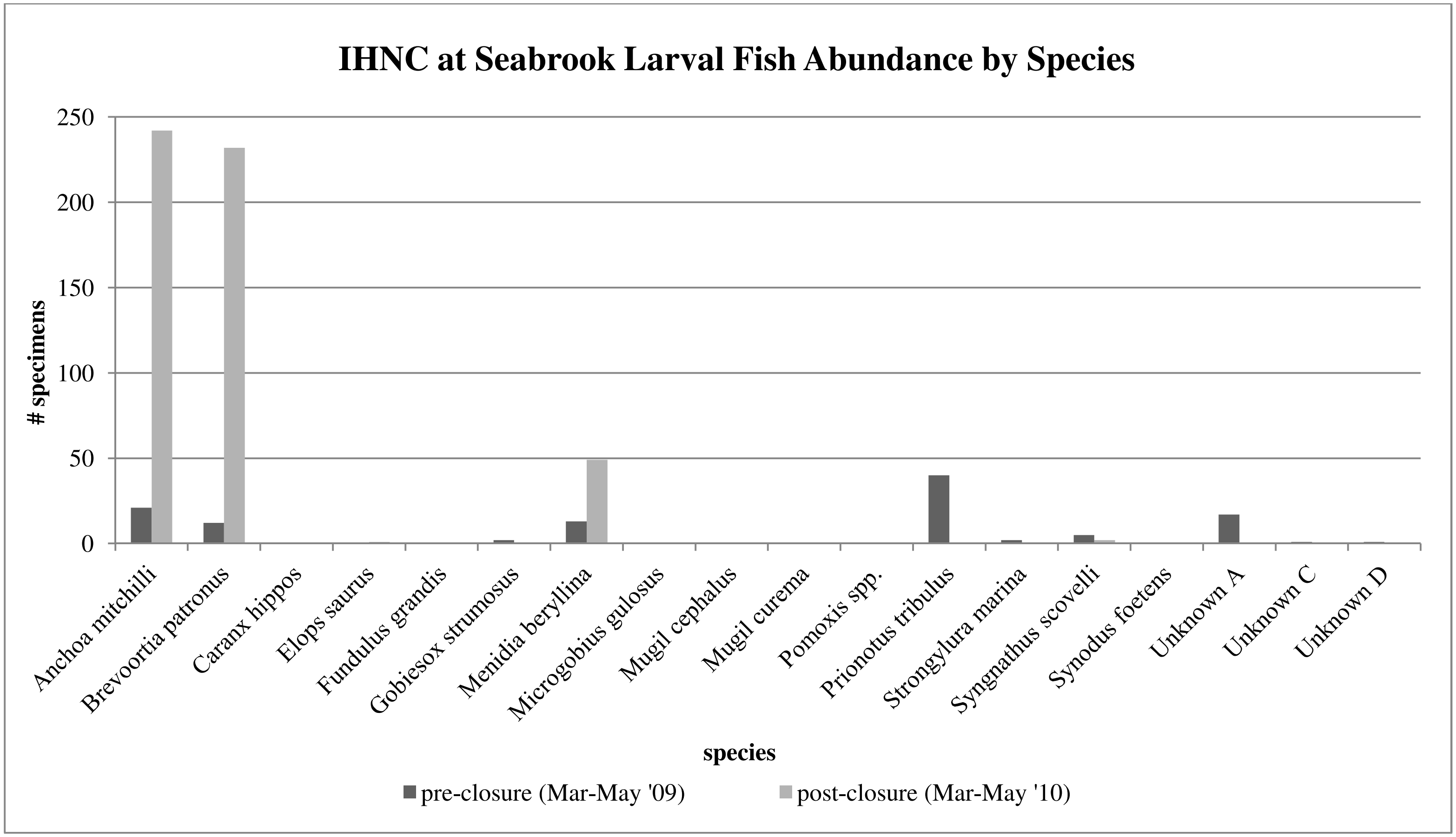


Figure 39. Abundance chart showing the number of specimens of each species found in the IHNC at Seabrook for a three-month period before the closure and the same three months (March, April, May) the year following the closure.

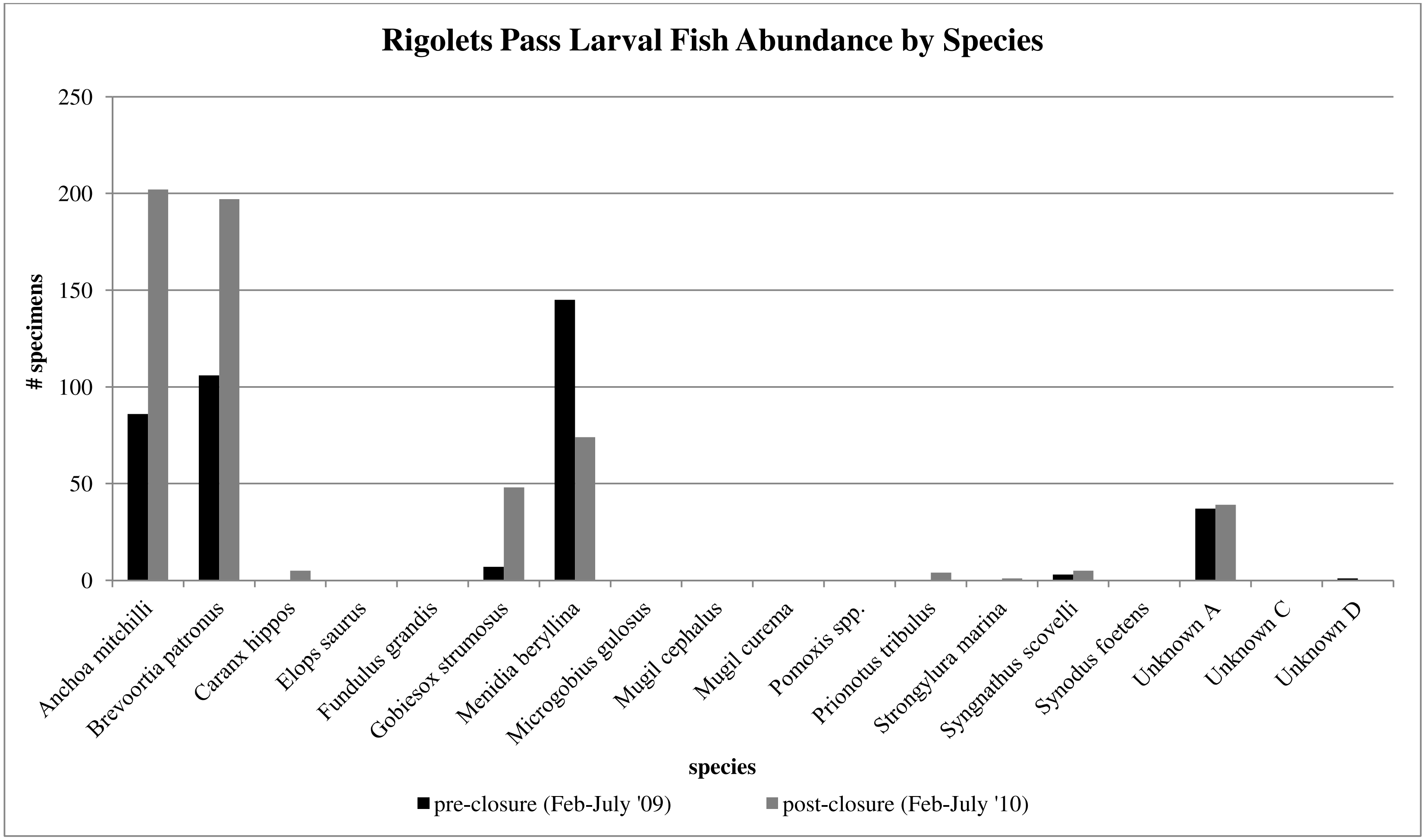


Figure 40. Abundance chart of the different species found in Rigolets Pass for a period of six months before the closure and the same corresponding six months following the closure, for comparison purposes.

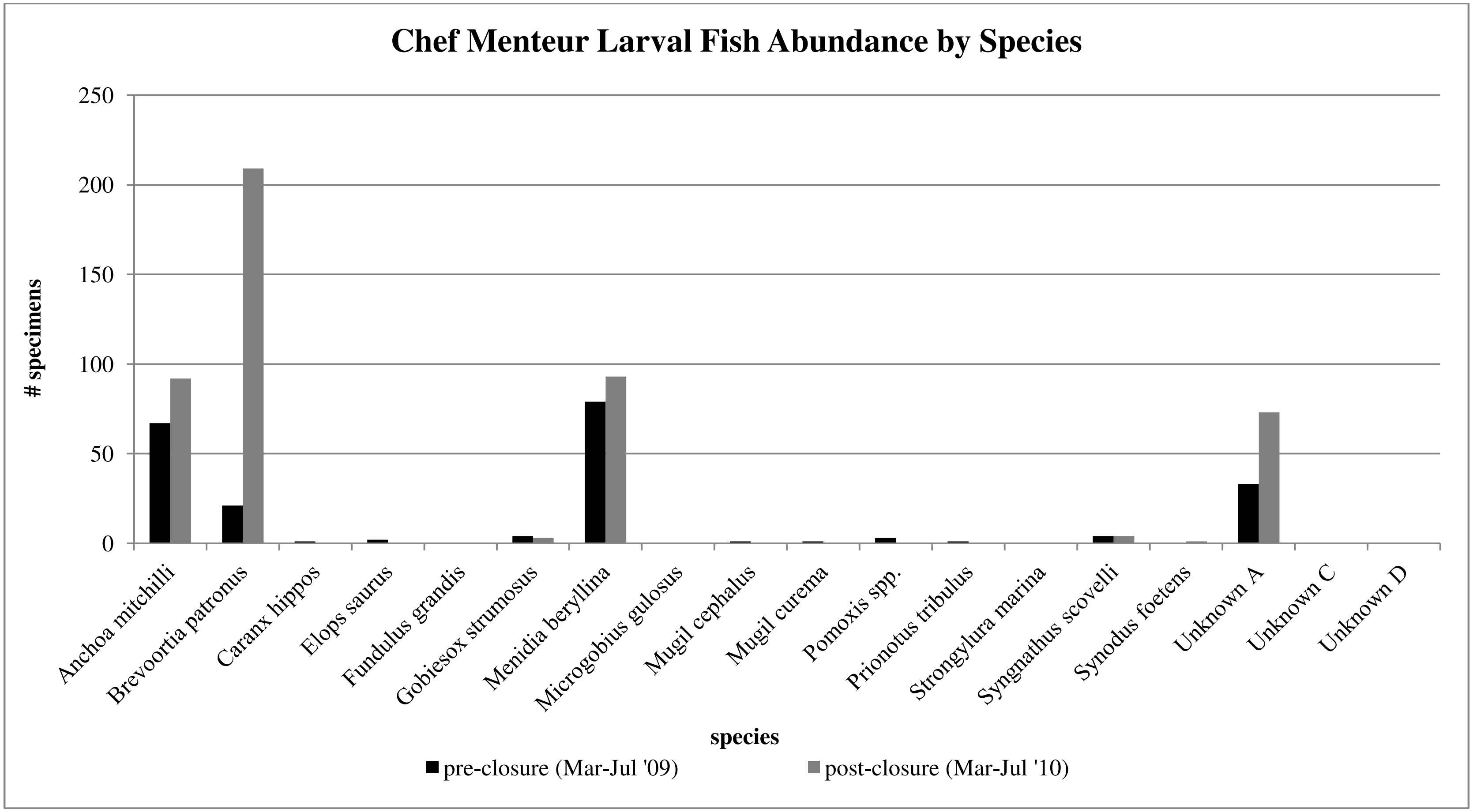


Figure 41. Abundance chart of the different species found in Chef Menteur Pass for a period of five months before the closure and the same corresponding six months following the closure, for comparison purposes.

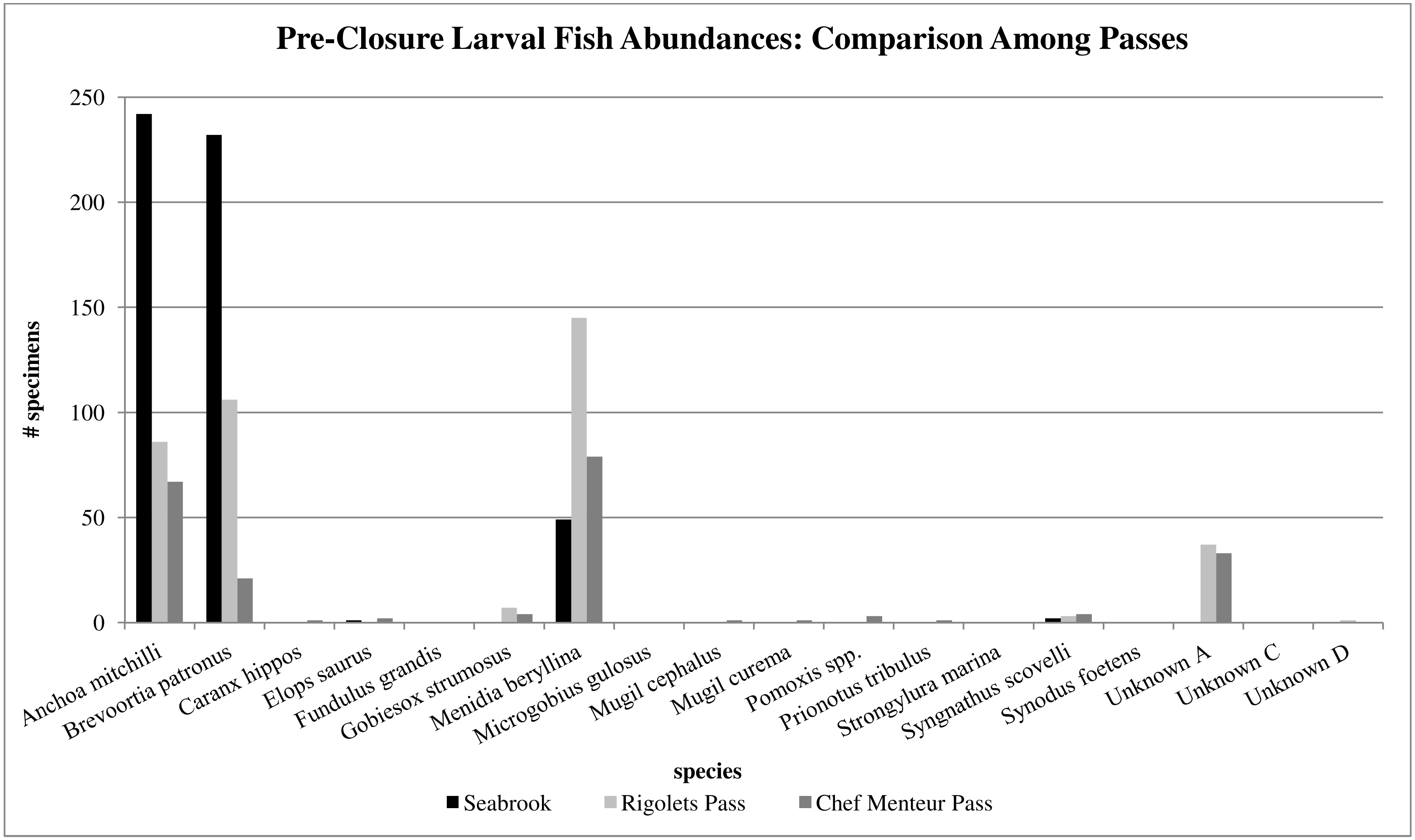


Figure 42. This chart shows comparisons for the species found at the three different passes prior to the MRGO closure (February 2009 to July 2009).

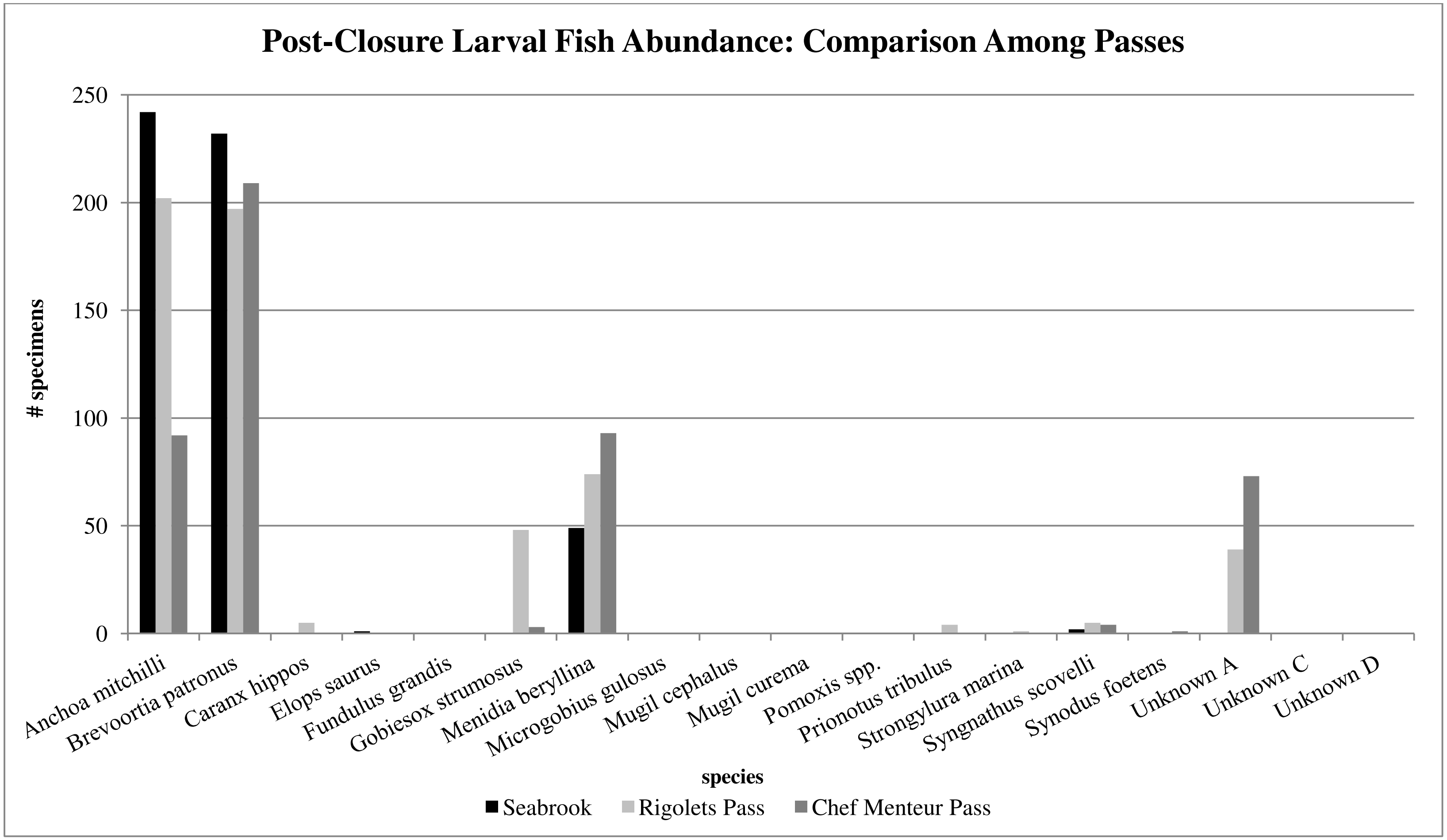


Figure 43. The chart compares the abundances of the different species among the passes after the closure of the MRGO (September 2009 to July 2010).

Table 15. The following table summarizes the species composition of the three tidal passes (the IHNC at Seabrook, Rigolets Pass, and Chef Menteur Pass) from the data collected prior to the MRGO closure, for the months corresponding to the pre-closure collection period for comparison purposes. Total abundance is given for each species.

Pre-closure			
species	Seabrook	Rigolets Pass	Chef Menteur Pass
Anchoa mitchilli	242	86	67
Brevoortia patronus	232	106	21
Caranx hippos	0	0	1
Elops saurus	1	0	2
Fundulus grandis	0	0	0
Gobiesox strumosus	0	7	4
Menidia beryllina	49	145	79
Microgobius gulosus	0	0	0
Mugil cephalus	0	0	1
Mugil curema	0	0	1
Pomoxis spp.	0	0	3
Prionotus tribulus	0	0	1
Strongylura marina	0	0	0
Syngnathus scovelli	2	3	4
Synodus foetens	0	0	0
Unknown A	0	37	33
Unknown C	0	0	0
Unknown D	0	1	0

Table 16. The table summarizes the post-closure species composition of the three passes, for the months corresponding to the post-closure collection period for comparison purposes. Total abundance is given for each species.

Post-closure			
species	Seabrook	Rigolets Pass	Chef Menteur Pass
Anchoa mitchilli	242	202	92
Brevoortia patronus	232	197	209
Caranx hippos	0	5	0
Elops saurus	1	0	0
Fundulus grandis	0	0	0
Gobiesox strumosus	0	48	3
Menidia beryllina	49	74	93
Microgobius gulosus	0	0	0
Mugil cephalus	0	0	0
Mugil curema	0	0	0
Pomoxis spp.	0	0	0
Prionotus tribulus	0	4	0
Strongylura marina	0	1	0
Syngnathus scovelli	2	5	4
Synodus foetens	0	0	1
Unknown A	0	39	73
Unknown C	0	0	0
Unknown D	0	0	0

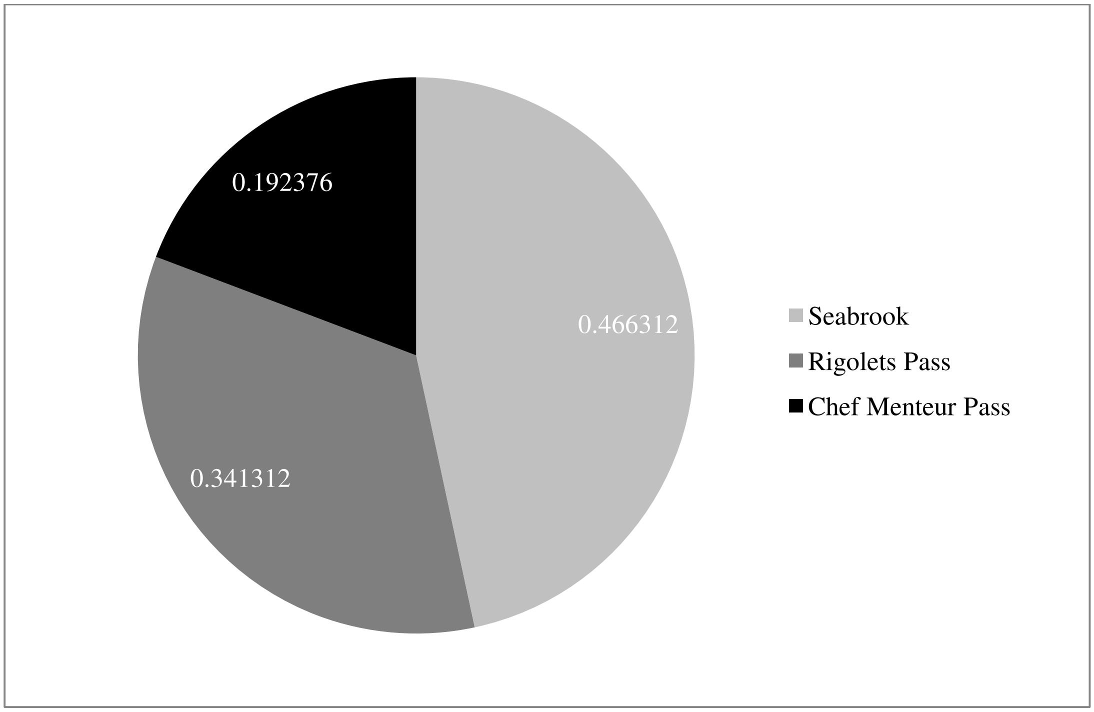


Figure 44. The pie chart shows the relative contributions of the three passes to the total larval fish abundance prior to the MRGO closure (February 2009 to July 2009).

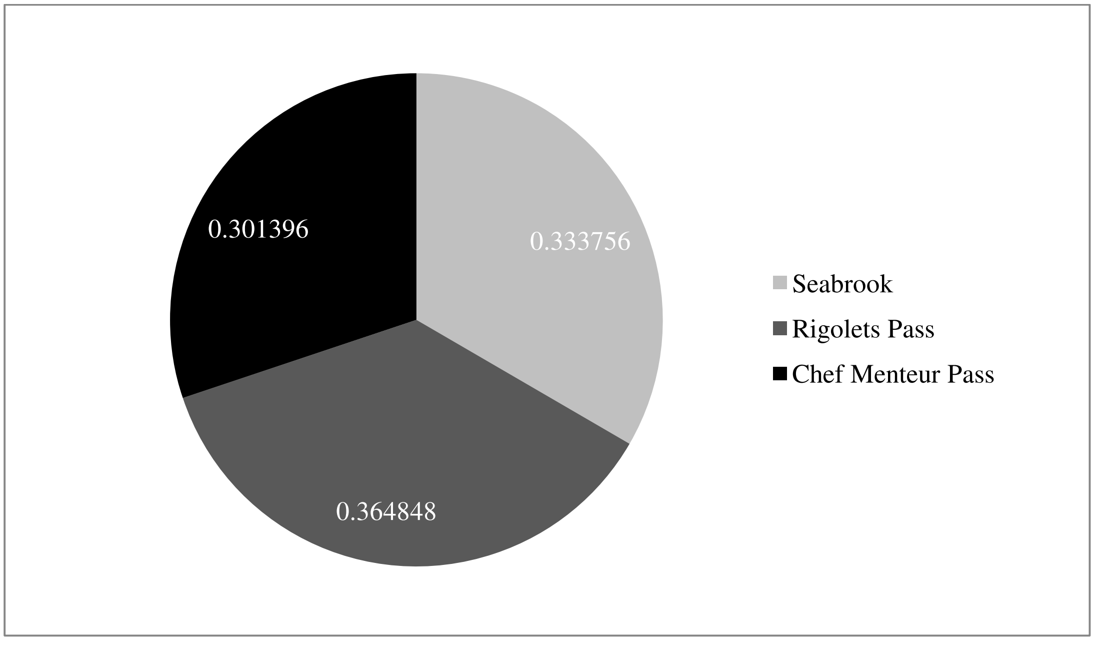


Figure 45. The pie chart shows the relative contributions of the three passes to the total larval fish abundance following the MRGO closure (September 2009 to July 2010).

Discussion

Although the results of the various multivariate analyses revealed no statistical differences in species compositions among sites or years for either the adult or larval fish samples, the data still give meaningful insight into the effects of the MRGO closure on the associated waterways and the biotic community that they support. Deeper investigation of salinity trends, dispersion characteristics of the assemblages, species composition, and utilization of the individual passes produced a greater understanding of the changes that have and are taking place.

Abiotic and Environmental Findings:

Previous studies have indicated that sampling periods of less than ten years are insufficient for determining trends in salinity changes, unless there is some significant modification to the existing hydrologic regime (Barrett, et al., 1990). Therefore, while the period for this study was relatively short, it is possible that some conclusions can be drawn about salinity changes in the area closest to the MRGO closure (i.e., the Seabrook site, P2) as the closure was certainly a major modification. Examining the salinity data taken during the collection of adult specimens, there were decreases in salinity at both P1 and P2, with a more marked decrease in salinity at P2 (Figs. 25 and 26). This follows expectations, as P2 is closer to the MRGO and is the site that has been more affected by its creation and subsequent closure. Site P1, at Irish Bayou, was used in this study for the purpose of comparison as it is the next closest site that the NRL has been collecting fisheries data. It is meaningful, however, that there were also detectable decreases in salinity at P1, which lies about 19.5 km northeast of Seabrook. This, of course, was over only a three year time period, and so it is not certain that this snapshot is indicative of any true salinity change as far away as Irish Bayou as related to the MRGO closure. Salinity changes in the Lake do follow seasonal variation and are affected by extreme weather patterns. On an annual basis, there is a fairly predictable rainy season from mid-December until mid-March with steady rainfall. May, October, and November are usually dry months, although there are periodic heavy rain events during this time (Kindinger, 2002). Assessing changes from pre- and post-closure from winter, spring, and late summer, there was a 4.2 decrease in salinity from February 2009 to February 2010. From May 2009 to May 2010 there was a 4.1 decrease, and from July 2009 to July 2010 there was a 5.0 decrease in salinity. With regards to P2/Seabrook, however, the decrease in salinity was steeper than that at P1/Irish Bayou and while there may have been some environmental variables such as high rainfall and low temperatures (leading to decreased evaporation), the effect of the MRGO closure here appears to be real even in a short period.

When looking for significant changes to salinity regimes, it is usually best to assess long-term data sets (Sikora and Kjerfve, 1985). The data taken from the LPBF monitoring sites spans a much greater period of time than the NRL data to draw more meaningful conclusions. Unfortunately, while the LPBF has provided salinity data from January 2001 to June 2013, their sampling protocol did not include any sites farther east than Pontchartrain Beach (Fig. 30). They did at one point collect water quality as far east as Lincoln Beach; however they ceased sampling at the site following Hurricane Katrina in 2005. The data taken by the LPBF over a 13.5 year period supported the evidence of the downward trend in salinity found from the NRL data at P1 and P2. The LPBF data showed decreasing salinity at the sampling sites nearest to the closure: Old Beach (at the mouth of Bayou St. John) and Pontchartrain Beach (Figs. 31 and 32). When examining the salinity changes here, it was apparent that there was a downward trend. This was verified by the regression analyses, and being over a time period of more than a decade, these changes were certainly real and not just due to fluctuating weather patterns.

Salinity data from the tidal passes taken at the time of larval fish collection revealed a downward trend both in the IHNC at Seabrook and in Chef Menteur Pass (Figs. 27 and 28), consistent with the salinity readings taken in the Lake during the adult fish collections. Rigolets Pass, on the other hand, showed a very slight increase in salinity over the sampling period (Fig. 29). The location of the pass, though, is far from the influences of the MRGO, and so is not representative of changes in the water quality related to the closure. The pass was being sampled solely for examination of migration into Lake Pontchartrain. Moreover, the Pearl River has a large influence on the conditions in the vicinity of Rigolets Pass (Sikora and Kjerfve, 1985). While freshwater input from the river generally keeps saltwater from the Gulf and Lake Borgne at bay, it is possible that river flow was decreased during the time the data show a slight increase in salinity in the pass.

The decreases in salinity since the closure are undeniable, and are a good indication that the health of the Lake near the plume of saltwater will begin to improve. The stabilization of salinity following the MRGO closure should be beneficial to Lake Pontchartrain fisheries. Fluctuating salinity presents a physiological challenge to fishes, even to the resilient fishes found in estuaries. It has been suggested that salinity changes are the primary limiting factor with regards to the distribution of fishes in estuaries (Norris et al., 2010). Evidence of changing conditions as far away as Irish Bayou from the data shown here is an additional indication that hopes for environmental restoration with the closure of the MRGO will indeed be realized. Other water quality indicators did not fluctuate very much with the decreasing salinity, but there may be a lag effect with regard to these. Water clarity and dissolved oxygen certainly should increase over time with the decreased saltwater intrusion. This, in turn, should lead to increases in SAV growth. Short-term and long-term changes in turbidity also affect the benthic community and food chain dynamics within the Lake (Turner, 1996). Increased habitat complexity has been found to result in higher densities of organisms (Etherington and Eggleston, 2000). Therefore, with more extensive SAV beds there should be an increase in the number of fishes in the area.

Biotic Findings:

Adult Data

Assessing the MDS plot for the adult data, it was apparent that P2 was more variable than P1, despite the analysis of similarity showing no statistically significant variation among years or groups at either site. Similar to salinity data, it is difficult to evaluate fish assemblages using short-term data sets. Long-term data are more useful for such analysis due to the dynamic nature of estuaries (O'Connell et al., 2004; Chavez-Lopez et al., 2005). The species composition at each site along with the results of the SIMPER analysis give a more detailed picture of the fish assemblages at the two sites and the relative dominance of the various species present (Figures 34-37; Table 4). The most dominant species at site P2 was *A. mitchilli*. This, of course, is the most abundant species in the Lake, and so its dominance is not surprising. That said, it is also a species that is capable of thriving in degraded habitats such as that provided at the Seabrook site as a result of anthropogenic activities such as the MRGO creation. It is an opportunistic species that can fill an open niche when other species cannot contend with degraded conditions. It was also one of the most dominant species at P1, with a 15.52% contribution, however its abundance at P2 was far higher with a contribution of 61.37%. The most dominant species at P1 was *M.*

beryllina, with a 52.8% contribution. This species generally prefers shallower, more sheltered habitats with a sandy bottom in lower salinity environments, which may explain its greater presence at P1 (Jones, 1978). Irish Bayou is sandy and the water is not very high in salinity. P2 has deep dredge holes and a very soft substrate. Another very common species in the Lake, B. *patronus,* also had a large influence on the assemblages at both sites, although there were more found at P2 than at P1. Following *A. mitchilli*, *A. hepsetus* was also shown to play a large role in the fish assemblage at P2. This is actually a bit more surprising at first glance, as *A. hepsetus* is generally found in higher salinity environments than Lake Pontchartrain. Initially, this seems counter-intuitive as one would expect the presence of the species more at P1/Irish Bayou which is nearer to the Gulf of Mexico. When taking into account the salt wedge entering the Lake from the MRGO via the IHNC at Seabrook, however, the presence of *A. hepsetus* is not so surprising. The presence of the species here is indicative of the previous connection of Lake Pontchartrain to the marine waters of the Gulf of Mexico by the MRGO. Despite P1 being situated closer to the Gulf, the direct route provided by the MRGO from the Gulf to the Lake historically would have made it easier for fishes to migrate into the Lake versus the complex marsh habitat between Irish Bayou and the Gulf of Mexico. This is also the case for the presence of *B. marinus*, although it was less abundant than *A. hepsetus*. Results of SIMPER analyses revealed that at site P2 there was a dominance of *A. mitchilli*, while at P1 there was a dominance of *M. beryllina* (Appendix I).

The species composition of the assemblages at the different sites gives a glimpse at the environmental history of the area in question. Historical anthropogenic impacts to Lake Pontchartrain have led to instability of fish assemblages (O'Connell et al., 2007). The greatest stressor in the P2 area was the saltwater intrusion resulting from the MRGO. This could be the major factor in the variability of the fish assemblage at P2, the site in the Lake closest to the MRGO. The previous connection to the Gulf of Mexico seems to have allowed more typically marine species to come into this area of the Lake. P2 is also situated in more of an urban landscape than P1, which could lend to more fluctuation in fish assemblages. The area is highly modified, with shoreline impoundment, bridges, buildings, and parking lots. The presence of a large area of impervious surfaces leads to greater stormwater runoff into surrounding waterways than in areas that have not been so greatly modified. P1, on the other hand, is more of a natural environment. There is a highway there, but the shoreline has not been modified to the extent of P2, and while it is a residential area, there are no large buildings and parking lots like the area surrounding Seabrook. The Seabrook site experiences a good deal of freshwater influx during high rain events, which allows for more typical freshwater species to enter the area. One such species that was observed during sampling following periods of high rainfall was Largemouth Bass (*Micropterus salmoides).* This species is a euryhaline fish that does well in a range of salinities, although it has been observed in Louisiana moving into fresher waters when salinity exceeds 5 (Meador and Kelso, 1989; Norris et al., 2010). Therefore, despite being a more typically freshwater species, *M. salmoides* may be able to disperse from fresher regions of the Lake to usually more saline environments during times of high precipitation. Some freshwater fishes also are pumped into the area from outfall canals during storms which could further explain their presence.

The SIMPER analysis showed agreement with the initial understanding of the MDS plots, where the fish assemblage at P2 appeared more variable than that of P1. The average similarity at P1 was 30% versus and average similarity of 11% at P2. Again, this follows the findings of previous studies in which the area of the Lake particularly in the vicinity of the

Seabrook location has a history of temporally unstable fish assemblages due the ecological history of the area (O'Connell et al., 2007). The more compromised habitat surrounding P2 which has led to instability of the fish assemblage there, coupled with typically more marine species travelling up the MRGO into the Lake, has resulted in a more variable fish assemblage at P2 when compared to P1.

There was an evident trend of decreasing salinity at P2/Seabrook (Fig. 26). While this was a relatively short-term data set, the LPBF sampling sites, which show salinity trends for a thirteen and a half year period, also indicated decreasing salinity. There was still, of course, seasonal variation in salinity; however the overall trend was downward. Despite the lack of significant findings when comparing pre- and post-closure fish assemblages at sites P1 and P2, the abiotic data for each collection were analyzed to determine if there was any correlation between environmental factors and fish assemblages. The results of the BIO-ENV analysis showed extremely weak correlations between the biotic and abiotic data. The most defining water quality parameter for P1 and P2 was the secchi depth, although this was a very low correlation (0.084; Table 5). Secchi disk transparency has been found to have a significant positive relationship with salinity in the Lake (Poirrier et al., 1992). As salinity decreases, dissolved oxygen and water clarity should increase. As the area recovers there should be a resurgence in the *Rangia* clam population due to the increased dissolved oxygen and decreased turbidity. With the recovery of this ecologically important species in the area the fish assemblage should also stabilize somewhat. For example, *M. undulatus* experienced large population declines in the past along with the depletion of the clams (Chavez-Lopez et al., 2005). As the *Rangia* clam numbers increase, there should be an increase in *M. undulatus* numbers as well as other estuarine species that inhabit the area. However, there is really no way of knowing how much of a lag there may be between water quality improvement and biotic recovery.

It was expected that correlations between the biotic and abiotic data would be weak as there were no significant differences in species composition among fish assemblages. Moreover, the findings are not surprising given the environment being studied. This does once again point to the resiliency of fishes in an estuary. While water quality factors generally have strong relationships to one another, whether that be inversely or directly related, they are constantly changing in an estuarine habitat. The salinity gradient presented by an estuary requires organisms to be tolerant of the variation for their survival. Their resilience to the changing environmental conditions of the estuary allows them to utilize this highly productive habitat for various life stages.

It is often difficult to find differences in estuarine fish assemblages as environmental conditions in estuaries are constantly fluctuating (Chavez-Lopez et al., 2005). Dispersion analysis, however, shows the variability within a particular assemblage for a given time. Again, the higher the relative multivariate dispersion (RMD) index, the more variable the assemblage. Higher variability within assemblages indicates instability, which often is indicative of a degraded habitat (O'Connell et al., 2006). Analysis of the adult fish data at P1 showed fairly low dispersion for both pre-closure (RMD = 0.359) and post-closure (RMD = 0.489). This indicates a mostly stable fish assemblage at Irish Bayou, which is in agreement with the relatively small amount of environmental modification at this site. The pre-closure data from the P2 site, on the other hand, showed a slightly higher dispersion (RMD = 0.830) than P1. As discussed above, this coincides with the more extensive anthropogenic influences in the urban Seabrook area. The fish assemblage here reflects the history of environmental modifications which has led to instability. The area had the usual estuarine-dependent fishes found in other parts of the Lake, in addition to more typically marine species that came up the MRGO plus more freshwater species during heavy rainfall. This combination created a more varied and more unstable assemblage than other areas such as P1.

Most interesting, however, is the change in dispersion from before the MRGO closure to after the closure at P2, with much greater dispersion occurring post-closure (RMD = 1.135). This high value is evidence of the modified hydrological regime induced by the construction of the rock wall closure. Despite the short time that elapsed during the period of data collection from before and after the closure, important changes were still captured. Over time, as the area recovers from the MRGO effects, the Seabrook fish assemblage may become less variable and more stable. Without the previous connection to the Gulf of Mexico via the MRGO there should no longer be an influx of marine species coming through the pass and into the Lake. There will still be some freshwater fishes during the times of year with high precipitation which will lend a degree of instability in the Seabrook area, but the extensive modifications along the shore in the Seabrook area will probably always result in a degree of variability in the associated fish assemblages. Despite this, as the hydrological regime and water quality factors become more stable over time the assemblage at P2 should stabilize somewhat, although the length of time until this occurs is uncertain. Additionally, the relatively healthy fish assemblages in other parts of the Lake may act as source populations which could aid in the recovery of the fish assemblages affected by the creation of the MRGO (O'Connell et al., 2009). Looking towards the future, the data from this study will be useful for investigating the effects of the MRGO closure over the long-term.

Larval Data

The various larval organisms present together comprise the zooplankton community. The zooplankton present in the estuary are an important source of nutrition for many fishes (Darnell, 1961). For example, the most abundant fish in Lake Pontchartrain, *A. mitchilli*, is a planktivore that feeds almost entirely on zooplankton. In turn, anchovies are an important prey item for larger fish in the estuary. Thus, the zooplankton community serves a vital role in the food web of the estuary. While this study focused on larval fish, or ichthyoplankton, there were many different types of zooplankton found in the larval samples. These included fish, crabs, penaeid shrimp, mysids, bivalves, jellyfish, isopods, copepods, and amphipods. Some of these are present all year, while the abundance of others, such as jellyfish, fluctuates seasonally.

Larval organisms have more stringent environmental requirements for their survival than do their adult counterparts. They are, however, still exposed to many different environmental variables such as temperature, salinity, and light gradients. These factors all influence larval behavior. For example, larval fishes have been found to be extremely sensitive to increases in salinity which often serves as a cue for eliciting depth-selective behaviors (DeVries et al., 1995). It was hypothesized that salinity changes would affect the larval fish assemblages in the tidal passes, however the analysis of the larval fish data showed no significant differences between pre- and post-closure larval fish assemblages in the upper portion of the water column (ANOSIM, R = 0.007, *p* = 0.354). It was further hypothesized that there would be a detectable change in the larval fish assemblage at least at Seabrook due to the physical closure of the MRGO, and that the expected decrease in larval migration through the MRGO could potentially coincide with increased larval influx through the natural tidal passes. The BIO-ENV analysis did show stronger correlations than that of the adult data, but the correlations were still fairly weak.

The lack of changes in the larval fish assemblage data were a bit more surprising than that of the adult fish assemblages, even though a previous study showed no relationships in short-term abundance of larval fishes with salinity (Allen and Barker, 1990). This finding seems to be in agreement with studies mentioned above, which indicated the inadequacy of utilizing short-term data sets for such studies. When possible, long-term data sets are much more beneficial for establishing trends (Sikora and Kjerfve, 1985; Barrett, et al., 1990; O'Connell et al., 2004; Chavez-Lopez et al., 2005). The construction of the rock closure, however, seemingly would have precluded organisms from coming through. Of course, the actual structure at the closure was not constructed as a solid wall across the entire water and marsh complex. The base of the structure is concrete rip-rap, which most probably still allows for some movement of organisms from the MRGO into the IHNC and then the Lake. Additionally, the movement of the water mass containing larval organisms does not just stop as it comes into contact with the closure, but rather is deflected into the surrounding area. There is a vast network of wetland habitat between the Gulf and the Lake, and larval organisms also may find their way through there as opposed to coming in solely through the tidal passes. Moreover, not all species found here are estuarine-dependent, moving offshore to spawn. Some are resident species, completing their life cycle within the estuary.

The SIMPER analysis determined that the most dominant species contributing to the fish assemblages in the three different passes were *A. mitchilli, B. patronus,* and *M. beryllina* (Tables 8-10). These species were also some of the most dominant fishes in the adult collections, indicating their overall importance throughout the Lake Pontchartrain ecosystem. Also present as some of the most dominant species in all three passes were *Syngnathus scovelli* (Gulf Pipefish) and *Gobiesox strumosus* (Skilletfish) among others (Appendix II).

The weak correlations found between the biotic and abiotic data were unsurprising due to the lack of statistically significant differences among the assemblages or from pre-closure and post –closure of the MRGO. As with the adult data, a dispersion analysis was performed to detect any variation within the assemblages after the initial analyses. The results of this were quite interesting, indicating that before the MRGO, Seabrook actually had the most stable ichthyoplankton assemblage of all three tidal passes (RMD = 0.712). This was followed by Rigolets Pass (RMD = 0.858) and then Chef Menteur Pass (RMD = 0.874). Following the closure, Chef Menteur Pass increased slightly (RMD = 0.997), and Rigolets Pass increased slightly more than that (RMD = 1.063). Seabrook exhibited the same post-closure dispersion index as Rigolets Pass (RMD = 1.063), but this is the biggest change from pre-closure dispersion indices. Seabrook, therefore, went from having the least variable larval fish assemblage before the MRGO closure to having the most variable assemblage after the closure. Moreover, the larval assemblage experienced about the same amount of change as did the adult assemblage. Again, this is indicative of shifts in the hydrological regime due to the construction of the rock wall, leading to fishery instability. In contrast to the between-sites comparison of the adult data (P1 versus P2), however, the larval fish data show less variability (lower dispersion index) at Seabrook as compared to the natural tidal passes (Chef Menteur Pass and Rigolets Pass). The reason for this is not entirely clear, but although Seabrook represents the artificial MRGO, there did not seem to be that much variation in the types of species coming in through the pass, with the exception of a few interesting findings.

Examining the species collected at Seabrook for the same corresponding months post-closure as pre-closure, *A. mitchilli* numbers were actually much higher post-closure (Fig. 39). This is indicative of them being resident species, and spawning locally as opposed to offshore.

The tidal passes are not a factor in their well-being. After the closure, *M. beryllina* was also found in greater numbers. At Rigolets Pass and Chef Pass, *A. mitchilli* and *B. patronus* were also higher post-closure, indicating that for some reason 2010 presented more favorable conditions for the two species. Overall there were relatively fewer species of fish found in the larval collections than the adult collections. One reason for this may be that some of the estuarine-dependent fishes that recruit to estuaries from offshore generally arrive in the estuary at more advanced developmental stages (e.g., *C. sapidus*), and so are not appearing in the larval samples (Boehlert and Mundy, 1988).

For many species there are pulses, or episodes of high abundances, of larvae through the tidal passes at different times of the year (Brown et al., 2004). Such pulses are common for estuarine-dependent fish and crustacean populations (Boehlert and Mundy, 1987; Hamer and Jenkins, 1997; Hettler et al., 1997; Brown et al., 2004). Some species that recruit to estuaries mostly during the cooler months include *S. ocellatus, M. undulatus, L. rhomboides, L. xanthurus,* and *P. cromis*. Most of these exhibit pulses of larvae coming into estuaries in January, with the exception of *P. cromis* which exhibits high numbers in both January and March. The peak spawning season for *M. undulatus* usually is November (Fruge and Truesdale, 1978). Species that recruit during the warmer months include *A. hepsetus, C. nebulosus,* and *C. arenarius.* These all are present in high numbers in estuaries in May and July, and some are also abundant in March (Holt et al., 1990).

Timing is an important factor in the recruitment of larvae to an estuary (Brown et al. 2004). The habitat surrounding the entrance of the MRGO into the Lake at Seabrook is by no means favorable for developing larvae. There has been extensive impoundment of the shoreline and there is little to no SAV in the area. In some situations, larvae are transported to suitable habitat, however they are not sufficiently developed for settlement. In this case, mortality may result because they are then transported away to less suitable habitats and are no longer able to settle in favorable environments once competent (Jackson and Strathmann, 1981; Brown et al., 2004).

Larval fishes, crabs, and shrimp entering Lake Pontchartrain through the natural tidal passes, Rigolets and Chef Menteur, have a high probability of encountering SAV beds in which they can settle out. The north shore of Lake Pontchartrain in particular has an abundance of healthy SAV habitat. Larvae entering the Lake through Rigolets Pass would most likely settle out here. Additionally, there are SAV beds in Lake Pontchartrain on either side of Chef Menteur Pass which provide suitable nursery habitat for those organisms utilizing that Pass. Unlike the natural passes, there is no sufficient SAV growth near the entrance to the IHNC at Seabrook. Despite increases in SAV growth since the cessation of shell dredging, the impacts to the shoreline do not currently allow for much growth along the south shore. The concrete flood wall that runs along the south shore, turbid waters from development and stormwater runoff, and other contaminants all have contributed to the decline in SAV in the area. While the MRGO has been shown to facilitate larval transport of important commercial species, such as *C. sapidus*, from the Gulf of Mexico into Lake Pontchartrain, these organisms did not have suitable habitat in which to recruit (Lyncker, 2008). Unlike larvae entering through either Chef Menteur or Rigolets Pass, those transported up the MRGO would have entered the Lake in a region lacking SAV, which would have greatly decreased their chances for survival. Moreover, the presence of the salt wedge at the Seabrook entrance and resulting hypoxia could have led to their demise before they were even able to move out of it. Some species of fish have been shown to delay transformation until they encounter suitable habitat (Pearcy et al., 1977; Boehlert and Mundy, 1988). With the widespread disappearance of SAV on the south shore, though, even delayed transformation would not help. High mortality would still result from the lack of suitable nursery habitat. Therefore, while the numbers of certain species entering the Lake may be decreased with the MRGO closure, the population may do better in the long-term with all larvae moving through the two natural passes. For instance, the Bighead Searobin (*Prionotus tribulus*) was collected in relatively high numbers at Seabrook before the closure, however there were no adult or juvenile specimens in the adult samples. Perhaps by coming into the Lake so quickly from the Gulf via MRGO the larvae were still too underdeveloped and did not possess great enough swimming ability to move out of the hypoxic conditions at Seabrook and in to more favorable waters.

Interestingly, the data show that *P. tribulus* was present in relatively much higher numbers before the closure of the MRGO than after (Fig. 39). In March, April and May of 2009 (pre-closure), forty larval *P. tribulus* specimens were collected, versus only two in the entire eleven-month collection period following the closure. It is an estuarine-dependent, ray-finned fish that is common in bays in the western Atlantic from Chesapeake Bay to northern Florida, and in the Gulf of Mexico from southern Florida to Texas. Its young are often found in estuaries. It grows up to fourteen inches, with smaller specimens common inshore. It is a bottom-feeder, eating mostly shrimp and worms. Based on the data, it certainly does appear that this was one fish species taking advantage of the artificial tidal pass to move from the Gulf of Mexico to the favorable habitat of Lake Pontchartrain. There were only four found in Rigolets Pass throughout the entire sampling period, and one in Chef Menteur Pass.

Figure 46. Image of a non-larval Bighead Searobin (*P. tribulus)* specimen measuring a total length of 1inch (image from sealitsoc.org, 2013). This species, which is not found in any of the adult collections, was present in relatively high numbers prior to the MRGO closure, while only two specimens were found in the post-closure ichthyoplankton collections. Characterization of larval forms is not available in literature.

Vertical salinity gradients and salinity changes in a water column are also important in inducing behavioral responses in larvae. The ability of larval fish to regulate their vertical position in the water column to enhance transport increases with age and size (Norcross and Shaw, 1984; Boehlert and Mundy, 1988; DeVries et al., 1995). The unnatural salt wedge at Seabrook probably would not have elicited the appropriate behavior. Unfortunately it is difficult to examine behavioral cues in the field, and it is likewise extremely difficult to recreate environmental conditions in a laboratory (Boehlert and Mundy, 1988). The actual effect of the salt wedge on ichthyoplankton behavior is therefore unknown. Survival rates of early life stage fishes coming into an estuary are extremely important for the commercial fisheries (Allen and Barker, 1990). Perhaps over time, as the physical conditions in the Lake along the south shore improve somewhat due the MRGO closure, there will be more SAV growth. This should lead to higher survival rates of larval fishes and, therefore, better fisheries should follow. There will probably always be relatively unstable fish assemblages along the urbanized south shore, though.

Examining the relative contributions of each pass toward the entire collection of larval fish, calculations showed that before the closure Seabrook had 46.6% of the fish, Rigolets Pass had 34.1%, and Chef Menteur Pass had 19.2%. Following the closure, for the same months as the pre-closure collection, Seabrook had 33.4%, Rigolets Pass had 36.5% and Chef Menteur Pass had 30.1% of the total larval fish collected (Figures 44 and 45). Relative contribution from Seabrook (which was expected to correspond with influx via the MRGO) decreased by 13.2%, Rigolets increased by 2.4%, and Chef Menteur increased by 10.9%. Despite no statistical differences found during ANOSIM calculations, it is rather interesting that while Seabrook decreased, both Chef Menteur and Rigolets increased. While Rigolets did not increase much, the almost 11% increase at Chef Menteur is fairly interesting given that it is closer in proximity to the MRGO. This could be due to mere chance, but one may suspect that larvae that previously might have entered the Lake through the MRGO and IHNC/Seabrook have altered their migration route to the Chef Menteur tidal pass. It is possible that the currents through the passes have shifted, leading to a slight (although not statistically significant) change in larval distribution. This would be consistent with predictions for shifts in flow distribution through the passes following the MRGO closure (Georgiou et al., 2009). The fairly stable larval contribution through Rigolets Pass shows that it is a consistent recruitment site, offering a combination of proximity to sources of larvae and the presence of nursery habitat (Etherington and Eggleston, 2000). It is relatively close to source populations of fishes that spawn in the Gulf of Mexico and this acts in concert with the healthy SAV growth along the north shore of the Lake near the pass to make it an important, stable conduit of recruits into the Lake.

The construction of the IHNC-Lake Borgne Surge Barrier at the “Golden Triangle” is likely more influential on the hydrological conditions at Seabrook and subsequently its ecology.

This large flood wall extends across the width of the triangle, with flood gates at the IHNC (Fig. 21, Fig. 22). By only having a small area open during most of the year when weather conditions are favorable, the current through the canal is greatly increased. This has the potential to affect the area in many negative ways, similar to those outlined in the report written by LPBF in response to the proposed flood protection structures across the Rigolets and Chef Menteur Passes (Lopez et al., 2011). The report shows how such as structure can have extremely detrimental impacts on the Lake Pontchartrain ecosystem by changing the hydrological conditions in the Passes and thereby changing the movement of organisms through the passes. Many organisms will no longer be able to navigate through the increased currents in the passes, thereby precluding their entry and exit from the Lake. Changes in currents could also negatively affect those species whose larvae have adapted to certain prevailing current conditions, and so larval organisms that could potentially still physically make their way into the Lake despite increased current velocities might not receive the proper cues to induce such behavior (Boehlert and Mundy, 1988). This has the potential to cause population crashes of many species of both commercial and non-commercial importance (Lopez et al., 2011).

There were some limitations to the larval study, including timing and the possibility of gear avoidance. There has been documentation of net avoidance by zooplankton that affects the accuracy of sampling, which in turn can lead to inaccurate population density estimates. Unfortunately, there is not much that can be done about this, aside from taking steps to attempt to minimize loss such as selecting plankton nets with small mouth areas and adjusting towing speeds (Fleminger and Clutter, 1965). The second limitation to the larval study was the sampling schedule. Night flood tides are important for some species entering estuaries through tidal inlets (Boehlert and Mundy, 1988; Churchill et al., 1999). This was a concern when planning the sampling schedule for this study, however it was not logistically possible with the available resources to sample at night. This plays a role in why there was not much variation in the fishes caught. By only sampling during the day, some species coming in through the passes were certainly missed. Likewise, available resources restricted larval sampling to only the surface waters, prohibiting sampling at the bottom of the water column and at mid-depths. The currents through the tidal passes are quite strong, and the equipment available for this study did not allow for more than surface water sampling. While some larval fishes come in at night, high in the water column, others come in during the day, but could be low in the water column. In a North Carolina estuary, it has been found that *L. xanthurus* comes into the estuary high in the water column during night flood tides, while *M. undulatus* stays deeper in the water column (Weinstein et al., 1980; Boehlert and Mundy, 1988). This is most likely due to the fact that *L. xanthurus* does not undergo diel vertical migration, so it should be more abundant in deeper waters (DeVries et al., 1995). Both of these species are present in Lake Pontchartrain, and so this study most likely neglected sampling for both along with numerous other species that similarly enter the Lake. Results of adult sampling validate these species in high abundance. Despite this lack of information, however, the purpose of this study was to assess assemblage changes, and although a complete picture of the water column from top to bottom was not necessarily given, the sampling was consistent over time and therefore sufficient for the goals of this project. For the purposes of assessing salinity changes and potential effects on larval recruitment, the restriction of sampling only in the surface waters is not detrimental, as the water in tidal passes is well-mixed. Also, other than the stratified region at Seabrook, Lake Pontchartrain is generally well-mixed. Other similar studies have assessed salinity changes by only monitoring the top 0.5 m of the surface waters (Sikora and Kjerfve, 1985; Wiseman et al., 1990). In the future, though, it would be beneficial to be able to sample the entire water column, both during nighttime and daytime flood tides. It has been found that most fishes are much more abundant toward the bottom of the water column, so the ability to collect larval specimens from lower in the water column would give a more complete assessment of larval recruitment to the Lake (Holt et al., 1990).

Larval influx into Lake Pontchartrain has yet to be fully characterized, and this could be extremely valuable information as state and federal agencies continue to discuss flood control options for the region. There has already been discussion of the construction of flood control structures (surge barriers) across the natural passes, which could have population-level impacts to the biotic community, as mentioned above (Lopez et al., 2011). There are many factors that control fish recruitment to suitable nursery habitats, including physical processes, which aid in the movement of larvae spawning grounds into estuarine nurseries through tidal passes (Brown et al., 2004). Circulation through the passes is one such factor that helps to supply estuarine nurseries with larvae from offshore spawning areas (Jenkins and Black, 1994; Jenkins et al., 1997; Brown et al., 2004). It is difficult, however to determine the controlling physical processes during recruitment events, as there is often a high degree of both spatial and temporal variability. This makes it difficult to determine large-scale patterns of recruitment (Brown et al., 2004). By building up a long-term database of information on larval organisms coming into the Lake through the natural tidal passes, more insight will be gained into just how entire cohorts of fishes and invertebrates may be affected by flood control measures. The data collected for this study are a good starting point.

The larval study also provides important baseline data for assessing changes related to the 2010 Deepwater Horizon oil spill. Several studies have used marine organisms as test subjects for observing responses to toxins from crude oil. The extensive effects of crude oil on fishes and invertebrates can have severe ecological consequences. Under the right conditions, whole cohorts of organisms could be exposed to oil and experience either short-term mortality or long-term sublethal effects. If an oil spill occurs in the vicinity of a species' spawning grounds during the spawning season, such cohort-level effects could occur. The Deepwater Horizon oil spill off the Louisiana coast is a prime example of such an occurrence. For example, while *C. sapidus* spawn year-round, the peak spawning periods are spring and fall. Therefore, the Deepwater Horizon spill coincided with the peak for its spring spawning. It is probable that the population of larval crabs newly hatched in the Gulf of Mexico and making their way back toward the Louisiana coastline was greatly affected. Unfortunately, we will not know the true extent of damage to this new cohort for some time or the possibility for declines in subsequent generations as lag effects are produced. Even if the oil was washed off of the crabs during molting, they could already have suffered long-term damage as a result of exposure to poly-aromatic hydrocarbons (PAH). Environmental contaminants, such as crude oil, can have deleterious effects on molting, growth, and limb regeneration in crustaceans (Weis et al., 1992). It has been found that even low-level exposure to PAHs can affect both molting and growth in juvenile invertebrates and that growth increments during molting are decreased when they have been exposed to toxicants such as PAHs (Weis et al., 1992; Oberdorster et al., 1999). Molting is necessary for crustacean growth (Mothershead and Hale, 1992). Therefore, if molting is disrupted due to oil exposure, *C. sapidus* population crashes could occur. Another physiological effect of crude oil exposure is changes in the gills of organisms. As the gills take in water for respiration, they are exposed to xenobiotics present in the water column. Sublethal effects on gill structure were observed during a study in which *C. sapidus* were exposed to naphthalene. It was found that the naphthalene exposure disrupts ion exchange in the gills which greatly affects oxygen transport (Sabourin, 1982). It has also been found that PAHs can block the gills and even result in necrosis, thereby inhibiting oxygen transport and resulting in death of the individual. The various effects of oil exposure on marine organisms are highly varied and complex, thus it could take years to know the scope of effects of the Deepwater Horizon oil spill on aquatic and marine organisms.

Aside from serving as baseline data for potential ecological shifts in the Lake due to physical modifications such as the construction of a surge barrier, or for serving as a comparison point for environmental disasters such as an oil spill, larval data are important for population assessments of fisheries. Fisheries research tends to focus on adult fishes, however larval and small juvenile forms are equally important for identifying trends in resources. Studies on the dispersal and recruitment of larvae throughout water bodies has become an important component in the establishment of protected areas, helping to guide agencies in what types of fishing practices will be allowed in different parts of a protected area. The study of larval organisms is also important for genetic studies of populations, showing the flow between adjacent populations, which is also an extremely useful conservation tool. The coupling of ichthyoplankton surveys with the more traditional adult fishery surveys allows for a greater understanding of the dynamics of a species' entire life cycle, enabling better management practices that help to ensure the perpetuation of the fishery.

SUMMARY

The closure of the MRGO was predicted to result in measurable changes in water quality, and adult, juvenile, and larval fish assemblages in Lake Pontchartrain and its associated tidal passes. Regression analysis of salinity data indicated significant decreases in salinity from the long-term data provided by the LPBF for Pontchartrain Beach and Old Beach at Bayou St. John (Pontchartrain Beach: $R^2 = 0.071_{(1, 653)}$, $p < 0.00$ a1; Old Beach: $R^2 = 0.076_{(1, 625)}$, $p < 0.001$). Multidimensional scaling plots visually indicated that P2/Seabrook was more variable than P1/Irish Bayou, however statistical analyses of adult and juvenile fish assemblage data from site P1 and site P2 did not show any statistically significant changes from the pre-and post-closure groups (ANOSIM, $R= -0.044$, $p = 0.88$) or between site groups (ANOSIM, $R= -0.0002$, $p= 0.5$).

Likewise, while MDS plots of larval data displayed visual differences among the tidal passes, analyses of the larval fish data from the two natural tidal passes (Rigolets Pass and Chef Menteur Pass) and the artificial tidal pass (the MRGO) did not show any statistically significant differences between site groups (ANOSIM, $R = 0.007$, $p = 0.354$) or between pre-closure and post-closure groups (ANOSIM, $R = -0.057$, $p = .918$). Dispersion analyses did indicate important changes in fish assemblages, however. Also, the species composition at each site and the relative larval influx through each pass gave important insight into ecological history of the area and the possible future of the fisheries. The study provides important baseline data for assessing long-term changes associated with the closure of the MRGO, as well as for the larval characterization of the Lake.

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Appendix I

```
 PRIMER     6/28/2013
Similarity
Create triangular similarity/distance matrix
Worksheet
File: E:\PRIMER Spreadsheets\Adult Biotic PRIMER.xls
Sample selection: All
Variable selection: All
Parameters
Analyse between: Samples
Similarity measure: Bray Curtis
Standardise: No
Transform: Square root
Outputs
Worksheet: Sheet1
MDS
Non-metric Multi-Dimensional Scaling
Similarity Matrix
File: Sheet1
Data type: Similarities
Sample selection: All
Best 3-d configuration (Stress: 0.01)
Sample                  1    2    3

STRESS VALUES
Repeat   3D      2D
    1  0.01     0.01
    2  0.01     0.01
    3  0.01     0.01
    4  0.01     0.01
```

```
   5  0.01      0.01
   6  0.01      0.01
   7  0.01      0.01
   8  0.01      0.01
   9  0.01      0.01
  10  0.01      0.01

** = Maximum number of iterations used

3-d : Minimum stress: 0.01 occurred 10 times
2-d : Minimum stress: 0.01 occurred 10 times

Outputs
Plot: Plot1
ANOSIM
Analysis of Similarities
Similarity Matrix
File: Sheet1
Data type: Similarities
Sample selection: All
Two-way crossed Analysis
Factor Values
Factor: Site
P1
P2

Factor: pre/post
pre
post
```

```
Factor Groups
Sample              Site  pre/post
TESTS FOR DIFFERENCES BETWEEN Site GROUPS
(averaged across all pre/post groups)
Global Test
Sample statistic (Global R): -0.044
Significance level of sample statistic: 88.3%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 882

TESTS FOR DIFFERENCES BETWEEN pre/post GROUPS
(averaged across all Site groups)
Global Test
Sample statistic (Global R): -0.002
Significance level of sample statistic: 50.5%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 504
Outputs
Plot: Plot2
Plot: Plot3

SIMPER
Similarity Percentages - species contributions
Worksheet
File: E:\PRIMER Spreadsheets\Adult Biotic PRIMER.xls
Sample selection: All
Variable selection: All
Parameters
Standardise data: No
Transform: Square root
```

```
Cut off for low contributions: 90.00%

Factor name: Site

Factor groups

P1

P2

Group P1

Average similarity: 30.07

Species                 Av.Abund  Av.Sim  Sim/SD  Contrib%  Cum.%

Menidia beryllina          48.63   15.88    1.46     52.80  52.80

Anchoa mitchilli          62.79    4.66    0.72     15.52  68.32

Mugil cephalus             2.13    1.22    0.41      4.05  72.37

Lucania parva             2.74    1.11    0.43      3.70  76.06

Leiostomus xanthurus        3.05    0.96    0.42      3.18  79.24

Lagodon rhomboides          2.68    0.94    0.42      3.12  82.37

Brevoortia patronus        28.29    0.89    0.21      2.95  85.32

Micropogonias undulatus      1.29    0.76    0.32      2.52  87.84

Fundulus grandis            1.11    0.69    0.36      2.30  90.14


Group P2

Average similarity: 11.64

Species                 Av.Abund  Av.Sim  Sim/SD  Contrib%  Cum.%

Anchoa mitchilli         269.36    7.14    0.38     61.37  61.37

Micropogonias undulatus      7.76    1.17    0.33     10.09  71.47

Anchoa hepsetus            82.91    0.60    0.12      5.15  76.62

Menidia beryllina           6.86    0.48    0.14      4.15  80.77

Brevoortia patronus       120.28    0.42    0.15      3.61  84.38

Leiostomus xanthurus        3.98    0.31    0.18      2.67  87.05

Microgobius gulosus         4.13    0.23    0.11      1.98  89.03

Bagre marinus              0.49    0.22    0.07      1.93  90.96

Groups P1  &  P2
```

```
Average dissimilarity = 88.44

                     Group P1  Group P2

Species               Av.Abund  Av.Abund  Av.Diss  Diss/SD  Contrib%  Cum.%

Anchoa mitchilli           62.79    269.36    20.38     0.90     23.04  23.04

Menidia beryllina          48.63      6.86    14.49     1.15     16.38  39.43

Brevoortia patronus        28.29    120.28     6.23     0.51      7.04  46.47

Anchoa hepsetus             0.71     82.91     4.94     0.34      5.59  52.06

Micropogonias undulatus      1.29      7.76     3.88     0.68      4.39  56.45

Mugil cephalus              2.13      2.65     3.26     0.66      3.69  60.14

Leiostomus xanthurus        3.05      3.98     3.18     0.70      3.60  63.74

Lucania parva               2.74      0.03     2.56     0.58      2.90  66.63

Lagodon rhomboides          2.68      0.23     2.27     0.69      2.56  69.20

Bairdiella chrysoura        2.68      1.65     1.96     0.40      2.22  71.42

Mugil curema                7.37      1.53     1.96     0.31      2.21  73.63

Membras martinica           0.61      6.43     1.78     0.25      2.02  75.64

Fundulus grandis            1.11      0.26     1.69     0.65      1.91  77.56

Cynoscion nebulosus         1.03      0.41     1.69     0.69      1.91  79.47

Strongylura marina          0.82      1.13     1.68     0.55      1.90  81.37

Syngnathus scovelli         1.84      0.02     1.60     0.56      1.80  83.17

Microgobius gulosus         0.00      4.13     1.58     0.28      1.78  84.95

Elops saurus                0.50      1.34     1.45     0.41      1.64  86.59

Cyprinodon variegatus       6.97      0.11     1.32     0.23      1.49  88.09

Sciaenops ocellatus         0.50      0.55     1.06     0.44      1.20  89.29

Cynoscion arenarius         0.87      0.21     1.05     0.51      1.18  90.47

Similarity

Create triangular similarity/distance matrix

Worksheet

File: E:\PRIMER Spreadsheets\Adult Abiotic PRIMER.xls

Sample selection: All

Variable selection: All
```

```
Parameters

Analyse between: Samples

Similarity measure: Euclidean distance

Standardise: No

Transform: None

Outputs

Worksheet: Sheet2

BIOENV

Biota and/or Environment matching

Worksheet

File: E:\PRIMER Spreadsheets\Adult Abiotic PRIMER.xls

Sample selection: All

Variable selection: All

Similarity Matrix

File: Sheet1

Data type: Similarities

Sample selection: All

Parameters

Rank correlation method: Spearman

Maximum number of variables: 5

Similarity Matrix Parameters for sample data worksheet:

Analyse between: Samples

Similarity measure: Euclidean distance

Standardise: No

Transform: None

Variables

  1 Water_temp

  2 Secchi

  3 Salinity

  4 Spec_cond
```

5 DO

Best results

No. Vars	Corr.	Selections
1	0.084	2
4	0.077	1-4
3	0.077	1,3,4
3	0.077	1,2,4
5	0.076	All
2	0.076	1,4
4	0.076	1,3-5
4	0.076	1,2,4,5
3	0.075	1,4,5
3	0.071	1-3

Appendix II

PRIMER 6/28/2013

Similarity

Create triangular similarity/distance matrix

Worksheet

File: E:\PRIMER Spreadsheets\Larval Biotic PRIMER.xls

Sample selection: All

Variable selection: All

Parameters

Analyse between: Samples

Similarity measure: Bray Curtis

Standardise: No

Transform: Square root

Outputs

Worksheet: Sheet3

ANOSIM

Analysis of Similarities

Similarity Matrix

File: Sheet3

Data type: Similarities

Sample selection: All

Two-way crossed Analysis

Factor Values

Factor: site

Rigolets

Chef

Seabrook

Factor: pre/post

pre

```
post

Factor Groups


TESTS FOR DIFFERENCES BETWEEN site GROUPS

(averaged across all pre/post groups)

Global Test

Sample statistic (Global R): 0.007

Significance level of sample statistic: 35.4%

Number of permutations: 999 (Random sample from a large number)

Number of permuted statistics greater than or equal to Global R: 353

Pairwise Tests

                     R  Significance     Possible       Actual  Number >=

Groups             Statistic      Level %  Permutations  Permutations   Observed

Rigolets, Chef         -0.004         49.4      Too Many          999        493

Rigolets, Seabrook      0.034          14.6      Too Many          999        145

Chef, Seabrook         -0.007          49.9      Too Many          999        498


TESTS FOR DIFFERENCES BETWEEN pre/post GROUPS

(averaged across all site groups)

Global Test

Sample statistic (Global R): -0.057

Significance level of sample statistic: 91.8%

Number of permutations: 999 (Random sample from a large number)

Number of permuted statistics greater than or equal to Global R: 917

    PRIMER     7/2/2013

Similarity

Create triangular similarity/distance matrix

Worksheet

File: E:\PRIMER Spreadsheets\Larval Biotic PRIMER 14B and 15C taken out for BIOENV.xls

Sample selection: All
```

Variable selection: All

Parameters

Analyse between: Samples

Similarity measure: Bray Curtis

Standardise: No

Transform: Square root

Outputs

Worksheet: Sheet1

Similarity

Create triangular similarity/distance matrix

Worksheet

File: E:\PRIMER Spreadsheets\Larval Abiotic PRIMER.xls

Sample selection: All

Variable selection: All

Parameters

Analyse between: Samples

Similarity measure: Euclidean distance

Standardise: No

Transform: None

Outputs

Worksheet: Sheet2

BIOENV

Biota and/or Environment matching

Worksheet

File: E:\PRIMER Spreadsheets\Larval Abiotic PRIMER.xls

Sample selection: All

Variable selection: All

Similarity Matrix

File: Sheet1

Data type: Similarities

```
Sample selection: All
Parameters
Rank correlation method: Spearman
Maximum number of variables: 5
Similarity Matrix Parameters for sample data worksheet:
Analyse between: Samples
Similarity measure: Euclidean distance
Standardise: No
Transform: None
Variables
  1 DO
  2 Spec. Cond.
  3 Salinity
  4 Temp.
Best results
No. Vars    Corr. Selections
       2    0.361 2,4
       3    0.358 2-4
       2    0.352 3,4
       1    0.334 4
       4    0.312 All
       3    0.312 1,2,4
       3    0.286 1,3,4
       2    0.266 1,4
       2    0.227 1,2
       3    0.218 1-3
Similarity
Create triangular similarity/distance matrix
Worksheet
File: E:\PRIMER Spreadsheets\Larval Biotic PRIMER.pri
```

```
Sample selection: All
Variable selection: All
Parameters
Analyse between: Samples
Similarity measure: Bray Curtis
Standardise: No
Transform: Square root
Outputs
Worksheet: Sheet3

SIMPER
Similarity Percentages - species contributions
Worksheet
File: E:\PRIMER Spreadsheets\Larval Biotic PRIMER.pri
Sample selection: All
Variable selection: All
Parameters
Standardise data: No
Transform: None
Factor groups
Rigolets
Chef
Seabrook
Group Rigolets
Average similarity: 14.24
Species             Av.Abund  Av.Sim   Sim/SD  Contrib%   Cum.%
Brevoortia patronus     10.62    9.68     0.47     67.99   67.99
Anchoa mitchilli        10.48    3.01     0.30     21.11   89.10
Menidia beryllina        7.55    0.78     0.19      5.50   94.60
Unknown A                2.62    0.26     0.18      1.84   96.44
```

```
Syngnathus scovelli      0.31    0.17     0.14      1.20   97.64
Prionotus tribulus       0.14    0.12     0.05      0.86   98.51
Gobiesox strumosus       1.90    0.11     0.12      0.80   99.31
Caranx hippos            0.17    0.10     0.05      0.69  100.00
Elops saurus             0.00    0.00  #######      0.00  100.00
Fundulus grandis         0.00    0.00  #######      0.00  100.00
Microgobius gulosus      0.00    0.00  #######      0.00  100.00
Mugil cephalus           0.00    0.00  #######      0.00  100.00
Mugil curema             0.00    0.00  #######      0.00  100.00
Pomoxis spp.             0.00    0.00  #######      0.00  100.00
Strongylura marina       0.03    0.00  #######      0.00  100.00
Synodus foetens          0.00    0.00  #######      0.00  100.00
Unknown C                0.00    0.00  #######      0.00  100.00
Unknown D                0.03    0.00  #######      0.00  100.00
Group Chef
Average similarity: 13.83
Species             Av.Abund  Av.Sim   Sim/SD  Contrib%   Cum.%
Brevoortia patronus      8.41    5.46     0.37     39.46   39.46
Anchoa mitchilli         5.93    4.34     0.38     31.38   70.83
Menidia beryllina        5.97    3.16     0.25     22.81   93.65
Unknown A                3.69    0.75     0.16      5.43   99.07
Syngnathus scovelli      0.28    0.07     0.10      0.48   99.55
Gobiesox strumosus       0.24    0.06     0.14      0.43   99.98
Elops saurus             0.07    0.00     0.05      0.02  100.00
Caranx hippos            0.03    0.00  #######      0.00  100.00
Fundulus grandis         0.00    0.00  #######      0.00  100.00
Microgobius gulosus      0.00    0.00  #######      0.00  100.00
Mugil cephalus           0.03    0.00  #######      0.00  100.00
Mugil curema             0.03    0.00  #######      0.00  100.00
Pomoxis spp.             0.10    0.00  #######      0.00  100.00
```

```
Prionotus tribulus      0.03    0.00  #######      0.00  100.00
Strongylura marina      0.00    0.00  #######      0.00  100.00
Synodus foetens         0.03    0.00  #######      0.00  100.00
Unknown C               0.00    0.00  #######      0.00  100.00
Unknown D               0.00    0.00  #######      0.00  100.00
Group Seabrook
Average similarity: 13.17
Species            Av.Abund  Av.Sim   Sim/SD  Contrib%   Cum.%
Menidia beryllina       2.48    4.74     0.36     35.96   35.96
Brevoortia patronus     9.10    3.97     0.30     30.16   66.11
Anchoa mitchilli        9.21    2.34     0.31     17.80   83.91
Prionotus tribulus      1.45    1.30     0.23      9.84   93.75
Syngnathus scovelli     0.31    0.71     0.15      5.41   99.16
Unknown A               0.59    0.08     0.05      0.61   99.77
Gobiesox strumosus      0.10    0.02     0.05      0.13   99.90
Strongylura marina      0.07    0.01     0.05      0.10  100.00
Caranx hippos           0.00    0.00  #######      0.00  100.00
Elops saurus            0.03    0.00  #######      0.00  100.00
Fundulus grandis        0.03    0.00  #######      0.00  100.00
Microgobius gulosus     0.00    0.00  #######      0.00  100.00
Mugil cephalus          0.00    0.00  #######      0.00  100.00
Mugil curema            0.00    0.00  #######      0.00  100.00
Pomoxis spp.            0.00    0.00  #######      0.00  100.00
Synodus foetens         0.00    0.00  #######      0.00  100.00
Unknown C               0.03    0.00  #######      0.00  100.00
Unknown D               0.03    0.00  #######      0.00  100.00
```

Groups Rigolets & Chef

Average dissimilarity = 86.20

	Group Rigolets	Group Chef				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Brevoortia patronus	10.62	8.41	32.48	1.08	37.69	37.69
Anchoa mitchilli	10.48	5.93	20.27	0.96	23.52	61.21
Menidia beryllina	7.55	5.97	14.85	0.78	17.23	78.44
Unknown A	2.62	3.69	8.15	0.48	9.45	87.89
Caranx hippos	0.17	0.03	3.05	0.25	3.54	91.43
Prionotus tribulus	0.14	0.03	2.42	0.22	2.81	94.24
Syngnathus scovelli	0.31	0.28	2.03	0.30	2.35	96.59
Gobiesox strumosus	1.90	0.24	1.77	0.43	2.05	98.64
Unknown D	0.03	0.00	0.49	0.16	0.57	99.21
Mugil cephalus	0.00	0.03	0.19	0.16	0.21	99.43
Pomoxis spp.	0.00	0.10	0.18	0.18	0.21	99.64
Mugil curema	0.00	0.03	0.14	0.17	0.17	99.80
Elops saurus	0.00	0.07	0.10	0.22	0.12	99.92
Synodus foetens	0.00	0.03	0.05	0.18	0.06	99.98
Strongylura marina	0.03	0.00	0.02	0.19	0.02	100.00
Fundulus grandis	0.00	0.00	0.00	#######	0.00	100.00
Microgobius gulosus	0.00	0.00	0.00	#######	0.00	100.00
Unknown C	0.00	0.00	0.00	#######	0.00	100.00

Groups Rigolets & Seabrook

Average dissimilarity = 87.87

	Group Rigolets	Group Seabrook				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Brevoortia patronus	10.62	9.10	31.69	1.09	36.07	36.07
Anchoa mitchilli	10.48	9.21	18.35	0.88	20.89	56.95
Menidia beryllina	7.55	2.48	17.38	0.73	19.78	76.73
Prionotus tribulus	0.14	1.45	7.65	0.47	8.71	85.44
Unknown A	2.62	0.59	3.55	0.46	4.04	89.48
Syngnathus scovelli	0.31	0.31	3.04	0.39	3.47	92.95
Caranx hippos	0.17	0.00	2.30	0.22	2.61	95.56
Gobiesox strumosus	1.90	0.10	2.08	0.39	2.36	97.93
Unknown D	0.03	0.03	0.83	0.21	0.94	98.87
Fundulus grandis	0.00	0.03	0.41	0.15	0.46	99.33
Unknown C	0.00	0.03	0.26	0.16	0.30	99.63
Strongylura marina	0.03	0.07	0.25	0.25	0.29	99.92
Elops saurus	0.00	0.03	0.07	0.18	0.08	100.00
Microgobius gulosus	0.00	0.00	0.00	#######	0.00	100.00
Mugil cephalus	0.00	0.00	0.00	#######	0.00	100.00
Mugil curema	0.00	0.00	0.00	#######	0.00	100.00
Pomoxis spp.	0.00	0.00	0.00	#######	0.00	100.00
Synodus foetens	0.00	0.00	0.00	#######	0.00	100.00

Groups Chef & Seabrook

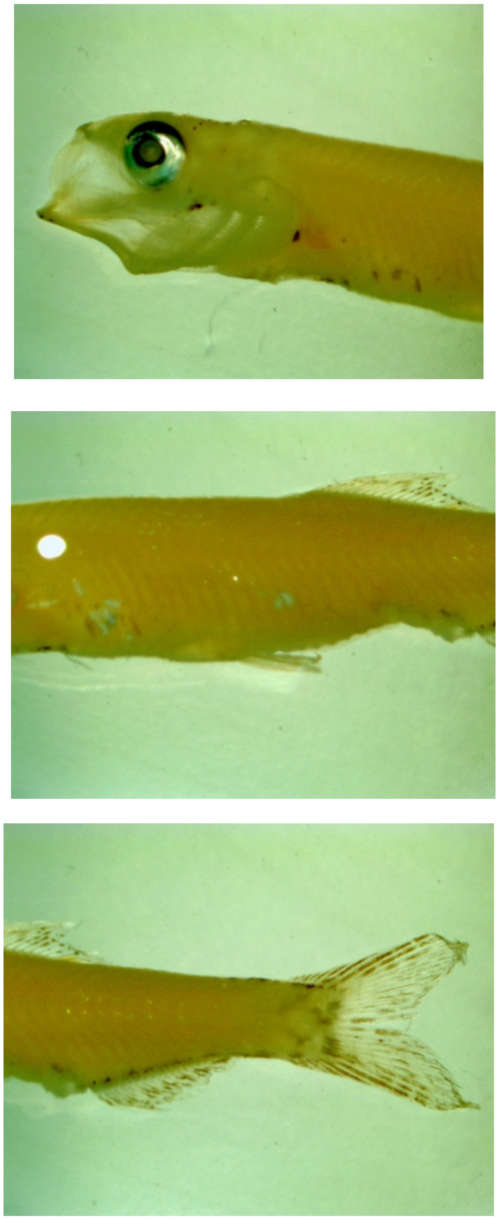
Average dissimilarity = 85.95

	Group Chef	Group Seabrook				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Brevoortia patronus	8.41	9.10	24.05	0.98	27.99	27.99
Menidia beryllina	5.97	2.48	19.57	0.79	22.77	50.75
Anchoa mitchilli	5.93	9.21	18.97	0.95	22.08	72.83
Unknown A	3.69	0.59	8.69	0.47	10.11	82.94
Prionotus tribulus	0.03	1.45	7.03	0.45	8.18	91.12
Syngnathus scovelli	0.28	0.31	3.26	0.40	3.79	94.91

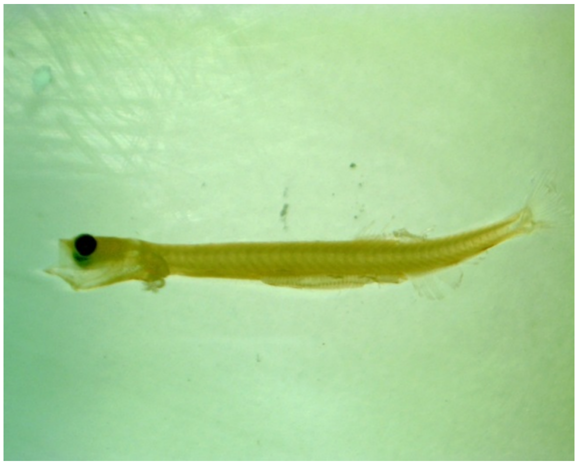
Gobiesox strumosus	0.24	0.10	1.25	0.29	1.46	96.36
Caranx hippos	0.03	0.00	0.75	0.15	0.87	97.23
Fundulus grandis	0.00	0.03	0.49	0.16	0.57	97.81
Unknown D	0.00	0.03	0.49	0.16	0.57	98.38
Unknown C	0.00	0.03	0.31	0.16	0.36	98.74
Strongylura marina	0.00	0.07	0.26	0.24	0.31	99.05
Mugil cephalus	0.03	0.00	0.21	0.17	0.25	99.30
Pomoxis spp.	0.10	0.00	0.20	0.18	0.23	99.53
Elops saurus	0.07	0.03	0.18	0.29	0.21	99.74
Mugil curema	0.03	0.00	0.16	0.18	0.19	99.94
Synodus foetens	0.03	0.00	0.05	0.18	0.06	100.00
Microgobius gulosus	0.00	0.00	0.00	#######	0.00	100.00

Appendix III

Brevoortia patronus



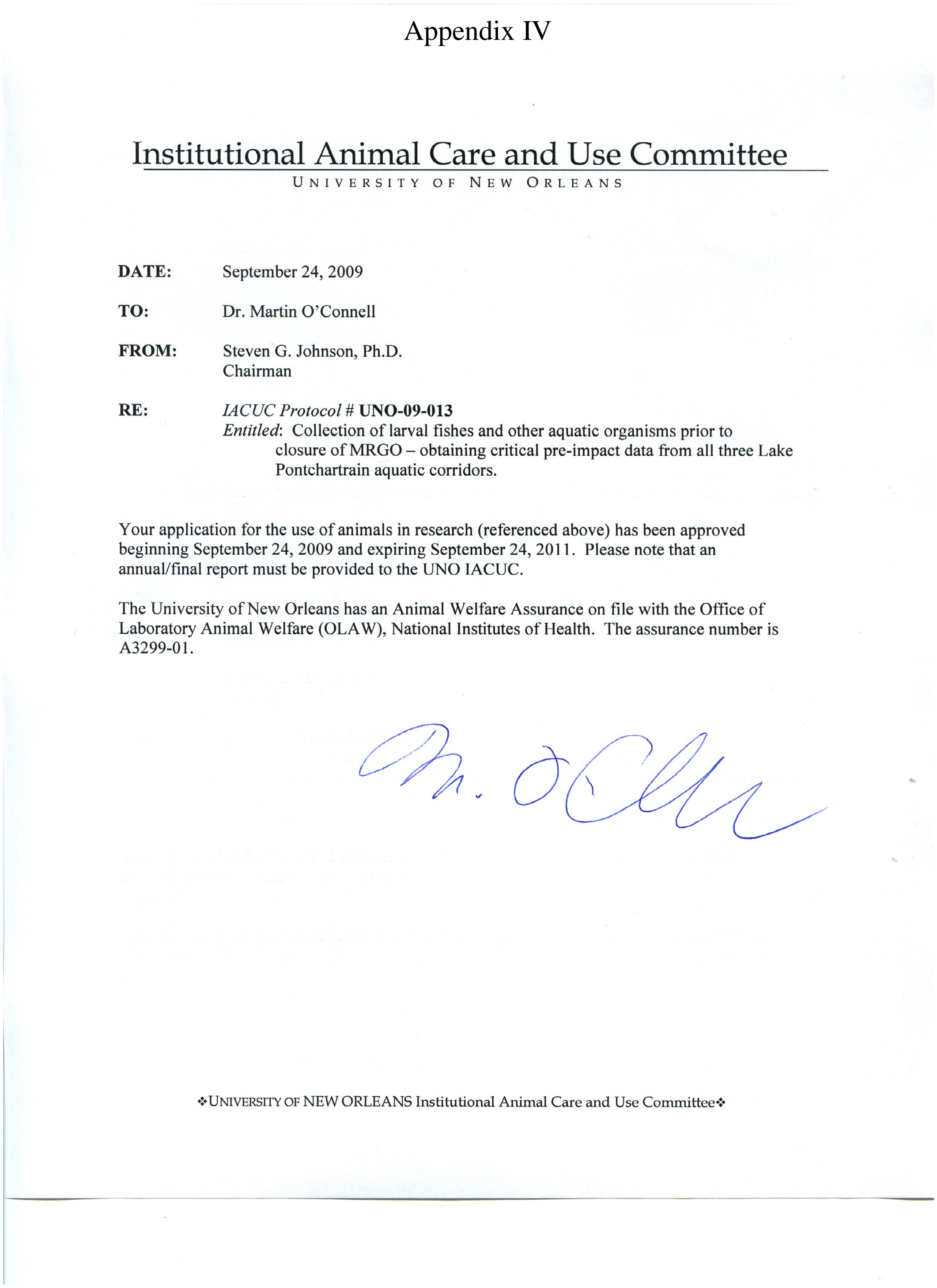
Anchoa mitchilli



Menidia beryllina

Gobiesox strumosus

Appendix IV



Institutional Animal Care and Use Committee

UNIVERSITY OF NEW ORLEANS

DATE: September 24, 2009

TO: Dr. Martin O'Connell

FROM: Steven G. Johnson, Ph.D.
Chairman

RE: *IACUC Protocol #* **UNO-09-013**
Entitled: Collection of larval fishes and other aquatic organisms prior to closure of MRGO – obtaining critical pre-impact data from all three Lake Pontchartrain aquatic corridors.

Your application for the use of animals in research (referenced above) has been approved beginning September 24, 2009 and expiring September 24, 2011. Please note that an annual/final report must be provided to the UNO IACUC.

The University of New Orleans has an Animal Welfare Assurance on file with the Office of Laboratory Animal Welfare (OLAW), National Institutes of Health. The assurance number is A3299-01.

❖UNIVERSITY OF NEW ORLEANS Institutional Animal Care and Use Committee❖

Vita

Rebecca Weatherall Cope was born and raised in New Orleans, LA where she was a student at Isidore Newman School. She then attended the University of Hawai'i at Hilo, where she received a Bachelor of Arts in both Biology (Ecology, Conservation, and Evolution) and Marine Science in 2004. She joined the Nekton Research Laboratory at the University of New Orleans in 2009 to pursue a Master's of Science in Environmental Science. She currently lives with her family in Waimea on the island of Hawai'i.