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Red drum (*Sciaenops ocellatus*) Habitat Use in an Urban System; Behavior of Reintroduced Fish in Bayou St. John, New Orleans

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Red drum (*Sciaenops ocellatus*) habitat use in an urban system; behavior of reintroduced fish in Bayou St. John, New Orleans.

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

Sunny J. Brogan

B.S. Southeastern Louisiana University, 2003

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Dedication

I dedicate this manuscript to my husband, Jason Ogle, for his support and encouragement throughout both good and not-so-good aspects of my graduate career. Thank you for understanding my ambitions and agreeing with me to pursue them.

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Abstract

Bayou St. John is a degraded water-body located within the City of New Orleans and is the focus of restoration efforts. I tested the ability of reintroduced red drum (*Sciaenops ocellatus*) to survive in this system and assessed their habitat use and behavior. I tracked 29 red drum fitted with external acoustic radio transmitters to determine if they could survive the degraded habitats and determine their general dispersion within the Bayou. All 29 tagged red drum exhibited post-stocking movement (i.e., survival) and occurred primarily in the northern section of the Bayou (nearest Lake Pontchartrain). To assess habitat use and behavior on a finer scale, a second group of 19 red drum were internally tagged with VEMCO transmitters and movements monitored by four remote receivers. These fish exhibited behavior similar to red drum in natural habitats. Monthly movements changed as temperatures changed but were not influenced by diurnal differences, salinity, or conductivity.

Keywords: *Sciaenops ocellatus*, telemetry, red drum, Bayou St. John, restoration

Introduction

For many years, conservationists have been trying to express the need for humans to set a limit on the level to which we will alter the environment. Humans should protect as well as respect not only the quality of the ecosystem in which they are living, but also the quality of ecosystems in which other species live (Leopold, 1949). Altering the landscape for human needs has been an ongoing primary factor that has caused the decline of fishery resources in aquatic ecosystems (Karr et al., 1985; Salo and Cundy, 1987). Restoring an ecosystem involves returning both structure and function to a system that was once natural (Fry, 2002). Managers often use a landscape ecology approach to better understand the impacts of changing habitats on organisms while also supporting decisions made by scientists about the influence of land-use disturbances on fishery resources (Forman and Godron, 1986). There are three main areas of concern in landscape ecology: 1. structural relationships among landscape elements; 2. functional interactions among these elements, including the flow of water, organic matter, nutrients, and species; and 3. natural and anthropogenic changes in structural and functional relationships of landscape elements over time (Schlosser, 1991). These three concerns must be addressed when managers are attempting to restore both functioning habitats and organisms that need these habitats.

When attempting to recover fish populations or fisheries, it is crucial to also restore as much of the terrestrial portion of the watershed as possible because both ecosystems are closely interconnected (Roni et al., 2002). Unfortunately, watershed and stream habitat restoration techniques such as structure placement, riparian planting, and reconnection of isolated habitats, have not been thoroughly evaluated, and their success is greatly debated within the scientific

community (Reeves et al., 1991; Kondolf, 1995; Kauffman et al., 1997). When restoring a system, appropriate habitat surroundings that are used for restoration should imitate the environment that once existed naturally and most probably sustained many different species (Beechie and Bolton 1999; Roni et al., 2002). Restoration of commercial and recreational fisheries is usually what draws the attention of most people, although it is equally important to restore the plant diversity and productivity in order to provide fishes with the necessary cover and habitat (Junk et al., 1989; Bayley, 1995).

Anthropogenic factors are the main cause of degradation and the need for restoration of aquatic systems. In Louisiana, multiple factors such as urban development, fishery over-exploitation, habitat alteration due to navigation, and other anthropogenic activities have left many of the coastal aquatic ecosystems significantly altered (Chesney et al., 2000). These types of exploitations and alterations have caused major ecological problems that limit and alter habitat that is essential to many aquatic species, including fishes and invertebrates (Zimmerman and Minello, 1984; Baltz et al., 1993). Historically, most cities and towns were built along the banks and shores of waterways. This development has increased the alteration of these water systems. For example, in Chesapeake Bay many waterways have been altered due to rapid urban expansion (Cairns and Palmer, 1995). Most of the current City of New Orleans was built from dredging Lake Pontchartrain sediment and dumping it into the marshy wetlands that once existed, to build up land for development of subdivisions and neighborhoods. In the Greater New Orleans Metropolitan Area (GNOMA), all water systems from the Mississippi River to the small bayous and wetlands that once existed naturally in the City have been channeled, redirected, altered into drainage canals, or filled in. Because of these anthropogenic changes, the fisheries in urban water ways have suffered extensively and restoration efforts have begun in

some areas. In areas such as these, many of the contributing pollutants could easily be reduced with small changes in urban lifestyle by teaching the urban residents some of the elements of natural systems (Cairns and Palmer, 1995). Because fishing has become more popular in urban areas, urban fishing programs have increased and several states have taken steps to either design urban fishing programs or restore existing programs (Alcorn, 1981). Aspects such as supplemental fish stocking and management techniques can influence overall fishing quality in urban waters to make improved fishing opportunities available for large numbers of people (Alcorn, 1981).

Louisiana consists of various types of aquatic systems including the Gulf of Mexico (GOM), freshwater rivers and bayous, tidal inlets, estuarine wetlands, lakes, salt marshes, and freshwater wetlands. Many of these systems also support abundant amounts of emergent plants and submersed aquatic vegetation (SAV). Productive fish habitats such as these are one reason Louisiana is known as the Sportsman's Paradise. Among all states, Louisiana is second only to Alaska in fishery production (Chesney et al., 2000). The aquatic ecosystems of Louisiana support important commercial organisms such as white shrimp (*Litopenaeus setiferus*), brown shrimp (*Farfantepenaeus aztecus*), blue crabs (*Calinectes sapidus*), and Gulf menhaden (*Brevoortia patronus*) along with the red drum (*Sciaenops ocellatus*), spotted seatrout (*Cynoscion nebulosus*), southern flounder (*Paralichthys lethostigma*), and sheepshead (*Archosargus probatocephalus*). The high quality habitat in Louisiana provides both a seasonal residence and nursery habitat for most of these estuarine-dependent fishes and invertebrates (Zimmerman and Minello, 1984; Baltz et al., 1993; 1998).

One of the most important estuarine-dependent sport fish in Louisiana is the red drum (*S. ocellatus*) or 'redfish'. The importance of red drum to Louisiana and the Gulf of Mexico spans

both the recreational and commercial fisheries (Simmons and Breuer, 1962; Mercer, 1984). Red drum are also important as estuarine-dependent predators in many places, ranging from Massachusetts to northern Mexico in the Gulf of Mexico (Lux and Mahoney, 1969; Mercer, 1984). They are the largest member of the Sciaenid family and are found from low-salinity and freshwater estuaries to offshore waters of at least 15 m (LSU, 2002). They will live over a variety of substrates such as soft mud, sand, hard shell clutch, and oyster reefs. Red drum are also known to congregate around artificial reefs and oil rigs (LSU, 2002). Because of its value, strict regulations have been enacted in many areas including the Gulf of Mexico to reduce the chances of overfishing red drum (Murphy and Taylor, 1990). Up until 1977 the red drum fishery was unregulated, though the growth of the offshore purse seine fishery prompted scientists to perform stock assessments and that year, regulations were put into effect. A combined daily limit of 50 red drum and spotted sea trout (*C. nebulosus*) was put into effect and were limited to no more than 2 red drum over 914.1 mm in length. In 1987, a minimum length of 355.6 mm was set. In 1988 the regulations were changed once again and the creel limit was reduced to 5 red drum with a minimum size of 406.4 mm and only one fish over 685.8 mm allowed. The reasoning for this was to reduce the fishing pressure on spawning size red drum. These same regulations are still in effect today and the red drum populations are very robust. Important red drum habitats such as areas around the mouths of passes and inlets where adults spawn from mid-August to mid-October also have protection from over fishing (Pearson, 1929; Peters and McMichael, 1987; Comyns et al., 1991). These passes and inlets are high salinity areas with increased current tidal flow, which are where most members of the drum family spawn. After spawning, larvae move inland with tidal movements and the juveniles eventually settle in estuarine nurseries, which are also important habitats that need protection (Holt et al., 1989;

Rooker and Holt, 1997). Even though most adult red drum move into the near Gulf to spawn, they are commonly found in estuarine habitats throughout the year (Patillo et al., 1997). Red drum are aggressive, opportunistic ambush predators with a diet consisting mostly of blue crabs (*C. sapidus*) as well as penaeid shrimp and some benthic fishes. This could explain the reason why they are very rapid growers. At one year of age, red drum average 330.2 mm in length and by year two, the average increases to 533.4 mm long with a weight of 1360-2721 g (LSU, 2002). At age 3, they will range in size from 508-711.2 mm and weigh 1814-4082 g. Once they reach this size, most will move offshore with few remaining inshore.

In Louisiana, the available habitat for estuarine-dependent fishes is mostly turbid waters with a muddy, silty substrate. It is difficult to study fishes in these deep and turbid rivers, streams, and bayous, therefore data must be obtained by capturing fish in their environment (Hynes, 1970; Tyus et al., 1984). Tracking the movement and activity patterns of fishes can be more easily accomplished by using ultrasonic and radio telemetry (Zeller, 1998). Radio telemetry is better suited for freshwater systems where the signal emitted by the transmitter is not obstructed by depth and conductance. Ultrasonic telemetry is better suited for estuarine and saltwater environments where depth and conductance do not interfere with the signal from the acoustic transmitter. Acoustic transmitters emit an ultrasonic sound, known as a ping, and can operate on a continuous or intermittent basis, dependent on the research objectives (George, 2007). The acoustic pings are detected by hydrophones that can either be used manually from a vessel or placed in an array throughout the study area by mooring them. In areas such as Louisiana where the river systems are often large, wide, and turbid, standard fish collecting methods cannot successfully sample all habitats and fishes cannot be visually observed. Ultrasonic and radio telemetry tools may be the best methods available to study the activities of

fish in areas where obtaining visual information is not possible (Tyus et al., 1984). Ultrasonic and radio telemetry have both been used primarily to obtain information about general fish movement and these methods offer great opportunities for movement pattern studies (Stasko and Pincock, 1977). Habitat choice information gained by ultrasonic and radio telemetry show more accuracy than data acquired from conventional fish collection techniques such as seines and rotenone (Tyus et al., 1984). Information concerning movement patterns and habitat requirements of fish populations are key components for effective management and habitat preservation (Bare, 2005). The home range concept has important implications for management such as species' movements in relation to its habitat, which can help determine environmental requirements. Home range data can also be useful in determining non-harvest areas and harvest quotas (Winter, 1977).

Historically red drum occurred in Bayou St. John, a waterway that runs through the center of New Orleans (Figure 1). Bayou St. John is an example of how habitat alteration and anthropogenic activities can degrade a once natural system. In the past, the natural Bayou ran from near the Mississippi River to Lake Pontchartrain, but over the last two centuries Bayou St. John has been dammed and its surrounding riparian zone developed by humans. The Bayou is approximately 6.5 km in length, ranges in width from 60 to 200 m, and has an average depth of about 2.7 m (Orleans Levee Board, 1996; *personal observation*). Because the Bayou had previously been connected to the Lake, it was consistently used by important estuarine-dependent fishery species such as red drum and spotted seatrout (Figure 2). In 1962, though, a flood-control structure was built near the opening to Lake Pontchartrain to prevent flooding and better manage decaying vegetation in the Bayou. This structure, also known as the “waterfall dam”, prevented most fish from accessing the Bayou (Figure 3). Currently, the flood control

structure has two round butterfly valves that are rusted in the opened position, leaving two openings of 1.5 m and 0.6 m (Figure 3). North of the “waterfall dam”, another flood control structure, known as the sector gates, was constructed in the 1980s (Figure 4). The openings for this newer structure are large, but have a 0.1 m mesh screen on the Lake side allowing water flow and small aquatic organisms through. This structure is maintained by the New Orleans Levee Board and is opened occasionally, when water levels in the Bayou are low. Other management activities in 1962 included dredging the Bayou multiple times and replacing natural shoreline with cement, both done as attempts to control plant growth in the Bayou and to “restructure vegetation”. As a result of this loss of connectivity to the Lake and the extensive habitat alteration, the Bayou St. John fishery has declined since the 1960s and the Louisiana Department of Wildlife and Fisheries (LDWF) has begun steps to restore it.

The goals of my research were to determine if red drum reintroduced into Bayou St. John could survive in this degraded system and, if so, then assess their habitat use and behavior while confined within the system. With this information I can determine if red drum stocked in Bayou St. John behave similarly to red drum studied in natural habitats. These results will help restoration efforts because if red drum habitat is found lacking, then future management efforts may be directed toward habitat improvement. More specifically I asked:

1. Can reintroduced red drum survive in Bayou St. John?
2. Do reintroduced red drum show habitat preferences within the Bayou?
3. Do reintroduced red drum behave naturally while confined within Bayou St. John?

Materials and Methods

Manual Tracking

To determine the survival, habitat use, and behavior of red drum reintroduced into Bayou St. John, I used two methods of tracking: manual tracking with Sonotronic acoustic radio telemetry and remote tracking with VR2W Vemco receivers. Manual tracking was conducted first from June 2007 to October 2008. I used acoustic radio telemetry to track an initial group of 29 red drum to assess their survival and general post-release dispersion within the Bayou. All 29 red drum were collected by hook and line in the Pontchartrain Basin east of the Mississippi River such that only fish native to the Pontchartrain Basin were released in Bayou St. John. These collections were made by the Nekton Research Laboratory (NRL) at the University of New Orleans. Personnel from the Aquarium of the Americas also donated a number of red drum that were fit only with Floy tags and then released. All 29 red drum (SL range = 490-584 mm, weight range = 2.08-3.57 kg) were brought to Bayou St. John in oxygenated and aerated coolers within 24 h of being collected and released at a common site in the northern portion of the Bayou (Site A in Figure 1). To minimize tagging mortality, Rejuvenade Next Generation[®], a stress reducer, was mixed into the live well water in the oxygenated coolers. Bags of ice were placed in the live well water to keep the water temperature cool for increased oxygen. Each of the 29 red drum were fitted with an external Acoustic Radio Transmitter, ART-01 (Figure 5), and released into the Bayou on different dates (Table 1). These transmitters (length = 105 mm, weight = 12 g) were attached using stainless steel wire inserted through two points in the dorsal musculature below the dorsal fin. Three shed transmitters were retrieved from the Bayou on 15 October 2007 and reused on three different red drum which were released at the south end of the Bayou on 1 November 2007. These three red drum were released at a more southern location

(Site C in Figure 1) to observe if their movement patterns would differ from those released at Site A.

The red drum were tracked from a boat using a Sonotronics MANTRAK kit (manual tracking kit) consisting of an Ultrasonic Receiver (Model USR-96) and a DH-4 directional hydrophone. Tracking surveys were conducted every one to two weeks from June 2007 to October 2008. Upon locating an individual red drum during tracking surveys, I measured water quality variables (water temperature, salinity, dissolved oxygen, percent saturation of oxygen, conductivity, and specific conductivity) at that locality to determine the environmental conditions of the habitat. These data were collected using a Yellow Springs Instrument 85 and GPS locality data were also recorded at each locality. This information was combined with topographic and depth data collected concurrently for another project (see bathymetry survey below).

I compared the manual tracking data with water quality data and analyzed them using PASW (SPSS) Statistics Grad Pack 17 (Predictive Analytics SoftWare - Statistical Package for the Social Sciences). Out of the 29 red drum that were reintroduced into Bayou St. John, I focused on 10 individuals with the most occurrence data (Table 1). These 10 focal red drum had an average length of 529.89 cm SL and average weight of 2.57 kg (Table 1). I chose these ten red drum based on the fact they had longer tracking times and that they were observed moving more than the other 19 red drum. I tested for possible differences in water quality data between the northern and southern regions of the Bayou because preliminary tracking data suggested a strong preference by the red drum for the northern portion of the Bayou. I also tested for differences in the width and depth of the Bayou between the northern and southern regions. Random habitat data were collected to act as a 'surrogate' red drum for comparisons among the

true habitat preferences of the real red drum. Because none of these initial 29 red drum were tracked south of the I-610 Bridge, any area south of this bridge was considered to be the southern regions of the Bayou and any area north of it to be the northern regions of the Bayou (Figure 1).

I compared environmental and habitat conditions chosen by the 10 focal red drum with random points within the Bayou to determine if red drum preferred habitats with specific environmental conditions such as higher or lower salinities, temperatures, and other water quality and habitat variables (e.g., width and depth). I conducted a multivariate analysis of variance (MANOVA) and used Bonferroni post-hoc tests to determine where significant differences ($\alpha < 0.05$) occurred among fish and random points. Because the red drum seemed to prefer the northern regions of the Bayou, I conducted a two-sample Kolmogorov-Smirnov test to determine if there were significant differences in water temperature, salinity, conductivity, specific conductivity, dissolved oxygen, and percent saturation of oxygen between the north and south regions of the Bayou. These variables were measured at 15 random points between the north and south regions. I also conducted a Kolmogorov-Smirnov test to determine if there were significant differences in width and depth between the north and south regions. These variables were measured at 20 random points in each of the north and south regions.

I used ArcMap to map movements of the focal 10 red drum throughout the entire study period. This was done by plotting GPS data collected while tracking these fish manually. My goal was to determine if the behavior of the tagged red drum was similar to other red drum as based on past research. In particular, I wanted to determine if red drum appeared to establish territories or overlap in their movements. The former would suggest that Bayou St. John resources are adequate for the red drum while the latter would suggest resource limitations. The data could also be used to determine if certain physical conditions (e.g., depth, width) appear to

be preferred.

Bathymetric Survey of Bayou St. John

To determine the depths of available habitats in Bayou St. John, I assisted in a bathymetry survey in summer 2008. The survey was carried out using an acoustic echosounding apparatus linked to a global positioning system (GPS). The data were collected as discrete XYZ points using a Differential Global Positioning Service (DGPS) and processed using a Geographical Information System (GIS) to produce a modeled surface of the Bayou bottom (Figure 6). Planned line files were used to navigate transects during the bathymetric survey. Cross-channel line spacing was set at 50 meters. Shore parallel lines were obtained approximately 4 m from the shoreline and through the center of the Bayou. These transects formed a dense grid of points between transect lines and the depth, latitude, and longitude were recorded along each transect. A single-beam echosounder was used in the survey for depth measurements and post-processed kinematic GPS for horizontal positions and elevations. An Odom Hydrographic Hydrotrac echosounder was used for sounding. The echosounder system was set to record soundings at a rate of 50 m/s and assumed velocity of sound through the water to be 1500 m/s. During the survey the static base station was set above the NGS benchmark on a survey tripod within 15 km of the area being surveyed. Sounding and GPS data were streamed in real-time to an onboard ruggedized notebook computer for data logging and navigation using Coastal Oceanographics HYPACK hydrographic survey software.

Depth measurements from the echosounder were integrated with the 3-dimensional XYZ GPS position to convert the depths to reference an Earth-centered ellipsoid model, eliminating errors associated with water surface elevation or tidally-based hydrographic surveys. The data

were then imported into ArcGIS 9.2 for mapping purposes. Contour lines were created using the ArcGIS Spatial Analyst extension and the Inverse Distance Weighting (IDW) method was used to interpolate depths between points.

Recapture Attempts

To assess growth and diet of the reintroduced tagged redfish, I attempted to recapture them on multiple occasions using 100 meter gillnets (2 m depth) with alternating mesh panels of 4.6 and 7.2 cm. While tracking, gillnets were fished for an hour at sites where transmitters were heard (Table 2). Gillnets proved unsuccessful, catching other fish species but no red drum. On 3 July 2008, electro-shocking efforts also proved unsuccessful. The high estuarine salinities in the Bayou were not compatible with our electrofisher. Hook and line was also used on multiple occasions during tracking efforts and four red drum were successfully recaptured on 14 December 2007 (Table 3). All four of these fish were caught at the northern end of the Bayou between the two flood-control structures. These fish were weighed, measured, and euthanized using MS-222 so that gut contents could be examined.

Remote Tracking

From October 2008 to July 2009, I used a more precise automated acoustic tracking method for a second set of 19 red drum to better determine habitat use and behavior on finer spatial and temporal scales. I used internal transmitters and moored receivers to track the finer-scale movements of these fish. As before, all reintroduced fish were collected by hook and line in the Pontchartrain Basin east of the Mississippi River such that only fish native to the Pontchartrain Basin were used (Table 4). Eleven red drum were collected by the Nekton

Research Laboratory (NRL) at the University of New Orleans and the remaining 8 were donated by the Gulf Coast Angler's Association. Of these, 11 red drum were released into Bayou St. John at Release Site B while the remaining 8 red drum were released at Release Site C, the southernmost region where the Bayou is closed to flow (Figure 1). The VEMCO V13-1L-69 KHz transmitters (Length = 52-96 mm, Diameter 13 mm, weight = 9-16 g) were surgically inserted into the peritoneal cavity of these fish (see surgery p. 16). Four VEMCO VR2W-coded acoustic receivers were deployed in an array throughout Bayou St. John to follow the hourly movements of the tagged red drum. The receivers were moored near the surface with the hydrophone pointing toward the bottom of the Bayou. The receivers were attached to a mooring line by zip cables with a buoy tied to the top and an anchor attached to the bottom. I chose to keep the receivers mobile so that they could be moved to monitor different regions of the Bayou (Table 5). As a tagged fish travels within the receiver range, the VR2W receivers record the identification number and time stamp from the V13 acoustic transmitter. Data were uploaded from the receivers into a computer via Bluetooth by boat every 7-14 d. Water quality variables (temperature, salinity, dissolved oxygen, conductivity, specific conductivity, and percent saturation of oxygen) and physical parameters (depth and width) were also recorded.

Out of an entire 8 months of automated tracking, I initially focused on a one month period where data collections were more abundant: 13 February – 20 March 2009. During this one month period, permanent YSI meters were deployed for constant water quality readings at 15 minute intervals. Using data generated from these permanent YSI meters, I was able to observe tidal period changes and water level changes. Therefore, I compared red drum activity with changes in temperature, water level, and salinity. I also compared red drum activity to determine whether they are more active during the day time or night time and also measured

their activity within tidal periods.

Sunrise and sunset during February –March 2009 occurred at 0600 and 1800, respectively. Day time activity for red drum was determined as the period 0600 to 1800 and night time activity was 1800 to 0600. Tidal data were split into 4 time periods (low, high, rising, and falling), then applied to red drum tracking data. Water temperature, salinity, and water level were split into categories of pre-change, during change, and post-change to observe red drum activity before, during, and after these major periods of change. The constant data readings from the permanent YSI meters were used to determine these changing periods (Figure 7). There were two cold fronts that occurred from 20 to 24 February 2009, where water temperatures decreased from 18°C-12°C and from 28 February to 4 March 2009, where water temperatures decreased from 19°C-13°C. One warm front occurred from 9 to 12 March 2009, where water temperatures reached the highest, increasing from 19°C-22.5°C. Three small salinity changing periods occurred; one from 16-18 February 2009, where salinities decreased from 6.2-5.7 psu, 23-16 February 2009, where salinities increased from 5.5-6.0 psu, and 14-17 March 2009 where salinities decreased from 5.8-5.4 psu. Three water level periods of change occurred: from 16-18 February 2009, where water level increased from 2.93 m to 3.08 m; from 21 to 26 February 2009, where water level decreased from 2.90 m to 2.29 m; and from 13 to 18 March 2009, where water level increased from 2.68 m-2.29 m. On 19 February 2009, the water levels in Bayou St. John began to decrease due to an open drain at Florida Avenue and on 23 February 2009, the sluice gates of the new flood control structure were opened to allow water from Lake Pontchartrain to flow into Bayou St. John. During this time, the water level in the Bayou dropped markedly (Figure 7). By 26 February 2009, water levels had returned to typical levels (Figure 7).

For this one month period, I tested for possible differences in red drum movement among periods by using non-parametric Kruskal-Wallis tests. This non-parametric approach was appropriate due to the large number of zeroes (representing no movement) in my data set. I defined a “move” as any time a red drum moved from an area covered by one receiver to an area covered by another receiver. I used these tests to determine if there were significant differences in red drum movement in relation to diurnal, water temperature, salinity, and tidal changes. These three physical variables were split into categories of “pre-change”, “during change”, and “post-change” to observe red drum activity before, during, and after these major periods of change. For example, to test for diurnal differences in red drum activity, for each 24 h period in my study month I compared the number of movements in day versus night. I repeated these analyses for each of the tagged 19 red drum then used a chi-square test to determine if the number of red drum showing significant movement patterns was different from random. For example, if 10 out of 19 red drum (roughly half) showed some significant movement pattern, it may not provide enough evidence that red drum as a whole are responding to a change in the variable. If, however, 18 of the 19 red drum showed some significant movement pattern, then a chi-square test could confirm that this is a significant trend.

Finally, I compared seasonal movements of red drum over the entire 9 month period (October 2008 to June 2009) to determine if movements increased during specific months by using non-parametric Kruskal-Wallis tests. For each of the 19 red drum, I compared the average daily number of movements among months. That is, I tested to determine if average daily movement was significantly different from October to November to December and so on. To further examine if changes in monthly movement were driven by environmental conditions, I used repeated measures ANOVA to test for differences in water temperature, salinity, and

conductivity among months. Repeated measures ANOVA was necessary to account for possible month-to-month interactions in environmental variables. For each month, nine readings for each of the three variables were measured and compared. As with the previous analyses, I used a chi-square test to determine if the number of red drum exhibiting significant movement patterns was different from random. Finally, I compared the pattern of average daily movement among months for all 19 red drum with the monthly pattern of each of the three environmental variables among months. My goal was to determine if red drum movement appeared associated with changes in any of the environmental variables.

Surgery

I surgically implanted internal transmitters into the body cavities of 19 red drum following procedures used on black drum (*Pogonias cromis*) in another Louisiana estuary (Gerald George, *personal communication*). Prior to surgery, an anesthetic bath and maintenance bath were prepared and surgery equipment, including the transmitter, was sanitized by soaking them in ethanol. An anesthetic bath was prepared using a solution of 100 mg/liter MS-222 which works by absorption through the gill tissue of the fish and sedates the fish. A maintenance bath was prepared by using a solution of 65 mg/liter MS-222 to partially sedate the fish. The maintenance bath was used to continuously pump through the gills of the fish during surgery to keep the fish at a constant level of sedation. A surgery table was made such that a wedge held the animal still during surgery while its position could be maintained (Courtois, 1981; LaVigne, 2001). The oxygenated cooler acted as the red drum's holding tank prior to surgery. From the holding tank a fish was placed in another cooler for the anesthetic bath and then placed back into the oxygenated cooler post surgery for recovery (Figure 8). As with the externally tagged fish,

the recovery cooler contained Rejuvenade Next Generation[®] to decrease the stress on the fish and increase the rate of recovery. Fish were anesthetized in the 100 mg/liter MS-222 solution 3-5 minutes prior to surgery. Once gill movement slowed, the fish were placed on the surgery table, dorsal side down, so the wedge on the surgery table would hold the fish securely. The 65 mg/liter MS-222 maintenance bath was pumped over the gills of the fish to keep the gills moist and the fish sedated. Scales were removed with a forceps from a small area on the ventral side of the fish, slightly below and between the pectoral fins. The transmitter was inserted and guided toward the posterior end of the fish. Absorbable monofilament sutures fastened by three surgical knots were used to close incisions. Next, length and weight were recorded for each fish and they were fitted with a Floy tag and placed back into the oxygenated cooler for recovery where they were closely monitored. Once all surgeries were completed and all fish recovered from surgery, they were transported to Bayou St. John in the oxygenated cooler and then released.

Results

Manual tracking

Of the 29 adult red drum released in Bayou St. John, the 10 focal red drum survived over 10 months (Table 1). Due to shed tags and lack of recaptures, it was difficult to determine how long each fish survived, but it is very likely that many red drum continued to live after tags were shed. For example, two of the redfish recaptured in December 2007 were not identifiable due to shed tags but both fish exhibited scars from having a transmitter attached to them, confirming they were fish from the study. These two fish also appeared to be healthy and active. It is also possible that some fish may have escaped through the flood control structures. The newer structure is opened occasionally and it is also possible that the four inch screen on the Lake

Pontchartrain side is rusted in some areas, which would provide large holes for escapement.

Although all 29 tagged redfish had also had Floy tags with phone contact information, no anglers reported any recaptures from the time of tagging until September 2009. Finally, all three red drum released at the southern end of the Bayou (Site C in Figure 1) moved to the northern end of the Bayou soon after being released (Table 1).

Based on MANOVA (with Bonferroni post hoc tests), conductivity, depth, and bayou width were found to be significantly different among some red drum habitats and random points within the Bayou ($p < 0.05$). Conductivity was significantly higher in habitats where fish 9, 20, and 22 occurred compared to random points (Bonferroni, $p = 0.043, 0.014, \text{ and } 0.026$, respectively; Figure 9). Seven of the ten focal fish (fish 2, 9, 11, 14, 15, 20, and 26) occurred at depths significantly deeper than random points (Bonferroni, $p = 0.2, 0.001, 0.044, 0, 0, 0.012, \text{ and } 0$, respectively; Figure 9). There were also significant differences in depth among fish, with fish 3 occurring in significantly shallower depths than fish 15 and 26 (Bonferroni, $p = 0.005 \text{ and } 0.001$, respectively; Figure 9). Fish 7 also occurred in significantly shallower depths when compared to fish 15 and 26 (Bonferroni, $p = 0.006 \text{ and } 0.002$, respectively; Figure 9). There were multiple significant differences among red drum regarding Bayou width where they occurred (Figure 10). The average width measured at random points was significantly smaller than the average width chosen by fish 7 and 22 (Bonferroni, $p < 0.001$ for both, Figure 10).

Based on MANOVA (with Bonferoni post hoc tests) width was found to be significantly different among some red drum habitats and random points within the Bayou ($p < 0.05$). In areas where fish 7 and 22 occurred, the Bayou was significantly wider compared to random points (MANOVA, Bonferroni post-hoc, $p < 0.01$ for both; Figure 10). Three of the ten focal fish (fish 3, 7, and 14) occurred at widths significantly different compared to fish 2 with fish 3 and 14

occurring in narrower regions compared to fish 2, and fish 7 occurring in wider regions compared to fish 2 (Bonferroni $p = 0.001$, 0.001 , and 0.019 , respectively; Figure 10). Five of the ten focal fish (fish 7, 9, 11, 22, and 26) occurred at widths significantly wider compared to fish 3 (Bonferroni $p = 0.001$, 0.02 , 0.005 , 0.001 , and 0.001 , respectively; Figure 10). Six of the ten focal fish (fish 9, 11, 14, 15, 20, and 26) occurred at widths significantly narrower than fish 7 (Bonferroni $p = 0.001$, 0.03 , 0.001 , 0.001 , and 0.001 respectively; Figure 10). Two of the ten focal fish (fish 22 and 26) occurred at widths significantly wider compared to fish 14 (Bonferroni $p = 0.001$, and 0.39 respectively; Figure 10). Fish 22 occurred at widths significantly wider compared to fish 15 (Bonferroni $p = 0.002$; Figure 10). Fish 22 also occurred at widths significantly wider compared to fish 20 (Bonferroni $p = 0.001$; Figure 10). There were no significant differences among random points and red drum habitats regarding water temperature, salinity, dissolved oxygen, percent saturation of oxygen, and specific conductivity.

There were no significant differences in the following environmental variables parameters between the north and south regions of Bayou St. John: (Kolmogorov-Smirnov test, temperature, $p = 0.833$; salinity, $p = 0.579$; dissolved oxygen, $p = 0.744$, percent saturation of oxygen, $p = 1.000$; conductivity, $p = 0.300$; specific conductivity, $p = 0.074$; Figure 11). There were also no significant differences in depth between the north and south regions (Kolmogorov-Smirnov test; $p = 0.978$; Figure 12). There were, however, significant differences in width between the north and south regions confirming that the northern region is significantly wider in areas than the southern region (Kolmogorov-Smirnov test; $p < 0.001$; Figure 13).

Mapping red drum occurrence data for the 10 focal organisms revealed that they preferred the northern section of Bayou St. John (Figure 14). Some red drum appeared to remain in territories that did not overlap with other red drum while the movement patterns of other

suggested their territories overlapped. In the section closer to the Lake, more territory overlap occurred while nearer to the Highway I-610 Overpass, red drum territories were non-overlapping (Figure 14). The bathymetric map of Bayou St. John (Figure 6) helped determine where deeper areas of the Bayou are located. Combining information from both of these maps, it is clear that red drum in Bayou St. John occur at multiple depths but tend to prefer deeper habitats.

Recapture Attempts

I compared initial length and weight data with data from two identifiable recaptured red drum and determined both had grown since their release date (Table 3). One fish released on 31 May 2007 and recaptured on 14 December 2007 (approximately 6.5 months) increased from 2,080 g, 490 mm SL to 2,340 g, 520 mm SL (Table 3). The second fish was released on 13 April 2007 and recaptured on 14 December 2007 (approximately 7.5 months) and increased from 2,670 g, 530 mm SL to 3,200 g, 575 mm SL (Table 3). Two of the four total recaptured fish were not identifiable due to shed tags. Both, however, exhibited scars from having a transmitter attached to them, proving that they had been tagged previously. These two fish also appeared to be healthy and active. Gut contents of three recaptured red drum were empty and one had a small (approximately 50 mm) blue crab (*Calinectes sapidus*) in its gut (Figure 15).

Remote Tracking

During the entire study period, receivers were strategically positioned and moved throughout the Bayou in order to detect spatial and temporal movement of reintroduced adult red drum (Figure 1). Most red drum showed fidelity to specific areas, particularly the northern regions of Bayou St. John. When red drum were released at two different sites, they exhibited

little or no differences in activity or habitat preference based on release site. The first 11 red drum were introduced at Site-B (Figure 1) on various dates occurring from 23 October 2008 to 26 November 2008 (Table 3). On 24 February 2009 the remaining eight transmitters were implanted into eight red drum and released at Site-C (Figure 1). All but two red drum (fish 28 and 29) were initially detected within 24 h of being released. These two fish were among the eight released at site C (Figure 1), the southern end of the Bayou. Their delayed detections suggest that they remained in the southern regions of the Bayou for about a week and a half before detection at receiver 4 (Figure 1). This was unusual behavior when compared to the other 17 fish which all moved north of receiver 4 within a few days of release. The remaining 6 red drum moved north toward receivers 4, 1-b, and 2 within 24 - 48 h. As with the other 11 previously reintroduced red drum, these fish also preferred the northern regions of the Bayou. Two of the eight red drum (fish 12 and 19) released at Site-B were continuous swimmers, showing movement among all 4 receiver locations along the Bayou, but still showing preference for the northern receiver locations. At the time of the final upload of movement data (16 June 2009), both of these red drum were at southern receiver locations (receivers 3 and 4).

Out of the 19 red drum, 16 were consistently heard from their day of introduction into Bayou St. John through 16 June 2009. Out of the 3 red drum that were not constantly heard (fish 11, 16, and 17), fish 17 was recaptured on 26 March 2009 by an angler, but fish 11 and 16 are currently unaccounted. Fish 11 was last heard on 8 March 2009 and fish 16 was last heard on 9 March 2009 (Table 3). Receivers were placed at the northern end of the Bayou specifically to monitor any red drum possibly escaping through the sector gates. Emigration from the study was ruled out due to no transient movements among these strategically placed receivers where the only escape option is located. Because the receivers do not completely overlap, it is possible that

these two red drum are located in an unmonitored location. However this is an unlikely assumption and would show peculiar behavior in these two fish in comparison to the remaining 15 red drum.

The 19 sub-adult red drum with internal VEMCO transmitters were introduced into Bayou St. John on different dates occurring between October 2008 and February 2009 (Table 3). To observe differences in activity, 11 red drum were released near the I-610 Bridge (Release Site B in Figure 1) in Bayou St. John and 8 were released at Lafitte Avenue (Release Site C in Figure 1), the southernmost region of the Bayou. During the one month initial focal period (13 February to 20 March 2009) most of the 19 adult red drum exhibited limited movement among receiver locations with the exception of 4 individuals (fish 2, 3, 11, and 16) that never moved out of the range (about 300 m) of a single receiver. Movement of red drum between receivers showed that the tagged red drum did survive in Bayou St. John. Due to lack of recaptures, though, I could not determine the condition, growth, or diet of these 19 fish. Along with the VEMCO tags, all 19 red drum were fitted with Floy tags that included contact information. One red drum (fish 17) was recaptured on 26 March 2009 by an angler 30 d after its release into the Bayou, however no usable data was obtained from this recapture (Table 3).

During the one month initial focal period, only two (fish 12 and 15) out of 19 red drum exhibited significant differences in movement in response to changes in temperature (Kruskal-Wallis; fish 12, $p = 0.040$; fish 15 $p = 0.045$; Figures 16 and 17). The increase in movement exhibited by fish 12 occurred from 8 to 13 March 2009 while temperatures were increasing, while “post-change” temperature movements occurred from March 8-17, 2009, and no movements occurred during “pre-change” temperature periods (Figure 16). The increase in movements in fish 15 occurred only “during change” of temperature, 28 February to 5 March

2009 and exhibited no movements within pre or post change in temperature periods (Figure 17). Fish 15 was the only red drum out of 19 that showed a significant difference in movement in relation to water level (Kruskal-Wallis: $p = 0.045$; Figure 18). These movements coincided with the dates of the previously mentioned temperature movements as well as the release date, 24 February 2009. Also, a portion of these data overlap with each other temporally because in some instances there was a time during a "post temperature period" that was also a "pre-temperature period" for another event. For example, if a front occurred close to a previous front, the post times for the first front and pre times for the next front overlapped.

During the focal month, there were no significant differences in red drum movement in response to diurnal, tidal, or salinity changes. None of the 19 red drum exhibited significant increases of night or day time movement during 13 February to 20 March 2009 (Kruskal-Wallis $p > 0.05$). Because of both flood control structures at its northern end, Bayou St. John experiences very little tidal flushing from Lake Pontchartrain, though a slight tidal response is present and measurable (Schindler, *pers. comm.*). The 19 red drum, though, did not respond to tidal changes with any significant changes in movement behavior (Kruskal-Wallis; $p > 0.05$). Salinity levels in Bayou St. John during the focal month seldom exhibited large changes, either over spatial or temporal scales (Figure 7) and red drum movement was not significantly influenced by any minor changes in salinity in Bayou St. John (Kruskal-Wallis $p > 0.05$).

Of the 19 red drum tracked over eight months, 14 exhibited significant (Kruskal-Wallis; $p < 0.05$) differences in average daily movements among months (Figures 19-21). A chi-square test confirmed that this proportion of fish (14 of 19) is significantly different from random ($\chi^2 = 4.263$, $p = 0.039$), suggesting that redfish in Bayou St. John move more in certain months than others. Average daily red drum movements were highest in December 2008 and then decreased

to their lowest level in March 2009 (Figures 19-21). After March, movements stayed relatively low for the remainder of the study period. When I compared average daily movement to water temperature (Figure 19), salinity (Figure 20), and conductivity (Figure 21), only water temperature appeared to have any clear relationship with red drum movement. As water temperature decreased from November to January, red drum movement remained high (Figure 19). As water temperatures increased from January to June, though, movements decreased to a low in March and then remained relatively low. No such pattern of a negative relationship was seen for either salinity (Figure 20) or conductivity (Figure 21). For water temperature, there were significant differences among all months except December and January (Repeated Measures ANOVA, overall $p < 0.001$). While the condition of sphericity was not met (Mauchly's $W < 0.001$), all three sphericity correction factors (Greenhouse-Geisser, Huynh Feldt, and the lower bound estimate) produced significant overall results.

Discussion

Manual Tracking

Red drum reintroduced into Bayou St. John survived for long periods (i.e., multiple months), showed preferences for wider and deeper habitats, and exhibited behavior similar to red drum in natural habitats. The reintroduced fish also exhibited a preference for the more northern regions of the Bayou which are closer to Lake Pontchartrain. Although a portion of the red drum tracked manually eventually lost their external tags and I had very few recaptures, it is likely that many red drum continued to live after tags were shed. For example, two of the four redfish recaptured in December 2007 were not identifiable due to shed tags but both fish exhibited scars from having a transmitter attached to them, confirming they were fish from the study. The low

number of recaptures limited the amount of gut content data I could analyze, however important results were obtained. The four recaptured red drum from December 2007 had empty guts, except one which contained a small blue crab. Information on the effects of impoundment on fish diets is limited, however it has been shown that some fishes can adjust their diet to exploit new food resources within the impoundment (Llanso, 1998). For example, in North Carolina, Miller and Dunn (1980) found that juvenile spot moving into impounded marshes of restricted access fed abundantly on new resources. Llanso (1998) found that red drum have flexibility in their diets and that red drum are generalist feeders and therefore would be expected to readily exploit new and abundant food resources in altered habitats such as those modified by impoundment. Unfortunately, after many attempts I was never able to recapture any more fish after December 2007. Reviewing other data collected in Bayou St. John by the Nekton Research Laboratory, food items available to red drum appear to be plentiful, consisting of blue crabs (*C. sapidus*), striped mullet (*Mugil cephalus*), and Gulf killifish (*Fundulus grandis*). It is well known that both blue crab and mullet are popular food items for red drum (Heffernan, 1973). Both of these species are commonly collected in the Bayou and may serve as prey for reintroduced red drum.

The limited food habit data for reintroduced red drum I was able to analyze are similar to those previously reported. In a natural, unaltered tidal regime, Llanso (1998) found that red drum >200 mm in size primarily fed on decapods and small fish, with decapods being the predominant food. However, in a restored, mangrove-rimmed impoundment, Llanso (1998) found polychaetes to be the main food items in red drum stomachs. *Cyprinodon variegatus*, *Poecilia latipinna*, *Gobiosoma robustum*, and *Bathygobius soporator* were identified in the stomachs of red drum in the unaltered regime with *C. variegatus* and *Menidia peninsulae* in

stomachs of red drum in the restored impoundment. Llanso (1998) suggested red drum have flexibility in their diets, showing no strong selectivity toward a specific prey in the natural site or strong avoidance of prey types in the restored site. In the Mississippi Sound, Overstreet and Heard (1978) found 59 taxa in the stomachs of three ontogenetic stages of red drum, with the most common taxa being crustaceans and fishes. Boothby and Avault (1971) considered red drum to be omnivorous feeders because more than half of the red drum stomachs studied contained more than two foods. Matlock (1990) suggested that, as with most sciaenids, diet varies with their size and space, likely because prey availability and size of prey change over time. I suspect with the high numbers of *C. sapidus*, *Mugil cephalus*, and *Fundulus grandis* in Bayou St. John (*personal observation*) that reintroduced red drum have a sufficient breadth of food items from which to choose and consume.

The manually tracked red drum exhibited no behavioral responses to differences in salinity and temperature (but see response of remotely tracked red drum below). Conductivity was the only water quality variable that seemed to influence these tagged red drum. A surf zone study along the Texas coastline also found that salinity did not appear to be a factor in red drum occurrence or availability (Heffernan, 1973). In a similar situation, another red drum survey found that although rain and river inflow causes salinities to be lower along the upper Texas coast when compared to the lower coast, juvenile red drum abundance is similar in both areas (Matlock, 1990). My results and these studies suggest that both adult and juvenile red drum are not greatly influenced by differences in salinity. Manually tracked red drum in Bayou St. John did, however, respond to the physical nature of their habitats, with most appearing to choose areas of the Bayou that were deeper and wider. Another study found that sub adults are more abundant along shorelines or shallow water than in open bay in fall and spring, but will

temporarily move to water > 1.3 m in depth to escape temperature extremes in winter (Matlock, 1990). Matlock et al. (1978) also reported highest gill net catches adjacent to deep holes just prior to passage of cold fronts indicating these fronts move fish to deeper water within estuaries. Bayou St. John's bathymetry, though, differs from that of a typical estuary. The Bayou's banks are shallow and the bottom gradually deepens toward the middle and does not have many, if any, deep escape holes. Over the sampling period, I most often tracked red drum in the middle of the Bayou but sometimes heard fish closer to the banks. Shed transmitters were found mostly along the banks of the Bayou, wrapped up in sticks and debris, indicating that red drum did occur at times in these shallower habitats along the banks.

Although tracking efforts were performed throughout the entire Bayou, red drum preferred the northern regions of the Bayou over the southern regions, although there were no significant differences between the two regions in regard to measured water quality variables. The physical differences between the two regions appeared to have been more of an influence on habitat preference more than water quality conditions. For example, the northern regions of the Bayou are wider than the southern regions. Habitat use varied among fish within the northern regions of the Bayou, with most fish preferring wider and deeper areas of the Bayou. By contrast, the southern region of the Bayou has more sloping concrete banks and increased urban activity than the northern region. Because red drum were never actively tracked in the southern portion of the Bayou, wider and less modified habitats seemed to be preferred over narrower and more concreted areas. However, fish were actively tracked between the two flood-control structures at the northern region of the Bayou where it is narrow and completely impounded. One possibility is that red drum were attracted to this narrow, shallow habitat in the northernmost region because this area has an abundance of food items which are flushed through the

newer sector gate from Lake Pontchartrain.

Remote Tracking

When reintroduced red drum were tracked remotely in Bayou St. John they exhibited behavior similar to red drum in natural habitats and showed a persistent affinity for specific areas. During the focal month of tracking (13 February to 20 March 2009), the majority of red drum did not appear to move based on the influence of local variables such as salinity, diurnal periods, and tidal periods. For example, changing water temperatures appeared to influence the movements of only 2 of the 19 red drum and fluctuating water levels only appeared to influence the movements of one tagged fish. Introducing red drum at two different sites did not influence their preference for a specific area, whether in the north or south region within the Bayou. In general during this month-long focal period, red drum showed little movement among receivers throughout the Bayou. One fish (#15) only showed movement in the immediate days after being released into the Bayou and never again moved during the focal month. These movements from #15 could be coincidence with the timing of reintroduction of the fish into the Bayou and not influenced by water level and temperature change at all. This initial behavior would be typical of reintroduced fish, many of which remained in motion for about a week after release before settling down. For example, another fish (#12) showed some typical movement in the immediate days after being released, then settled down. Two weeks later, though, fish #12 moved again, suggesting that temperature could have been an influence in the movement of this particular fish. However, fish #12 exhibited more movement during this focal period than most fish, suggesting that this particular fish is a “swimmer”. However, because only a small number of fish showed increase of movements with changing temperature and water level during this focal time period,

it is possible that these movements are not related to these water changes at all. In a similar study, red drum detections in a tidal creek declined with upriver distance from the release point, showing that sub-adult red drum preferred their release point for the structure or habitat (Dresser and Kneib, 2007). I observed no fidelity to the release site for any of the Bayou St. John red drum. It should be noted, though, that the Dresser and Kneib (2007) study area was a much smaller area compared to Bayou St. John. It also differed from the Bayou because it is open to the estuary and the fish have an option to migrate in or out of the tidal creek.

Bayou St. John receives very little tidal flushing from Lake Pontchartrain, but I did observe that measurable tidal periods occur in the Bayou. These slight changes in water level, though, did not appear to trigger changes in red drum movement. However it has been shown in other studies that red drum are influenced by tides in areas that are heavily tidally influenced such as natural estuaries and nearshore areas. Heffernan (1973) found that physical conditions of the surf zone, such as tide phase and current, appeared to have major influences on fish abundance and feeding. Red drum became more abundant during incoming tides and moderate currents and the poorest fishing success was associated with outgoing tides or periods with strong currents paralleling the beach. Dresser and Kneib (2007) showed that aggregations of subadult red drum appeared restricted to specific areas and times, especially during low and mid-tides. The Bayou St. John red drum did not exhibit this behavior in relation to tides and I suggest that the tidal signal was too small to trigger any behavioral response. If future restoration efforts allow a more natural connection between the Bayou and Lake Pontchartrain, red drum may show more movement in response to larger tidal changes.

Red drum movements were also not influenced by day or night time in Bayou St. John during the month-long focal period. However, Dresser and Kneib (2007) found red drum

movement to be influenced by complicated movement patterns of crepuscular and nocturnal effects along with patterns of alternating flood tides. This study was conducted in Georgia where red drum habitat is mainly intertidal marshes and creeks which are highly influenced by tide. Similarly, another day/night study (Heffernan, 1973) that used multiple gear types to show activity patterns in red drum indicated movement and feeding activity occurred during both daylight and dark periods with red drum availability determined more by tide phases and temperature responses than photoperiods. As mentioned before, Bayou St. John has only a very small influence from tide and there are no marshy habitats available. Therefore, feeding activity in the Bayou would not likely be determined by tide. Perhaps the lack of movement I observed during the focal month is due to a lack of any real marsh habitat in Bayou St. John. It would be interesting to determine if the restoration of marsh plants in the future would stimulate red drum movement.

During the time of my research, salinity did not change markedly, therefore red drum did not exhibit preferences to different or changing salinities within the Bayou. In a study conducted in Palmico Sound, North Carolina, Bacheler (2009) found habitat use patterns in sub-adult red drum were related to the age of the fish and was sometimes region-dependent. In some instances, preferences for these factors differed between age-1 and age-2 red drum. For example, age 1 red drum were primarily captured at 2 different salinity ranges (0-5 psu and 20-30 psu) while age 2 red drum abundance was not related to salinity. Also, smaller scale analysis of age 2 red drum in a small tributary off Neuse River showed a negative response to salinity but a positive response to dissolved oxygen (Bacheler et al., 2009). Other studies, however, have generated findings more similar to my own. Two separate red drum studies along surf zones on the Texas coastline found that salinity did not appear to be a factor in red drum availability and

even though salinities were lower along the upper coast versus higher salinities along the lower coast, red drum abundance was similar in both areas (Heffernan, 1973; Matlock, 1990). Because the Bayou St. John red drum did not respond to the slight changes in salinity during the focal month, I suggest that this will not be a major factor in determining the success or failure of future reintroduction attempts, mostly because of the known tolerance of red drum to a wide range of salinities (Pattillo et al., 1995).

Red drum did show differences in average daily movements among months, suggesting movements may be influenced by seasonal or temperature changes. Similar to this study, other studies have shown that temperature and seasonal changes in temperature do influence red drum abundance. For example, Adams and Tremain (2000) also noted seasonal movements to optimal habitats by juvenile red drum have been observed in other estuarine systems and are likely related to changes in water temperature, salinity, or prey availability. In the Palmico Sound, Bacheler (2009) showed a positive relationship between age-2 red drum and temperature, but only in the Neuse River and Outer Banks regions. Bacheler (2009) notes that this response to temperature was most likely not a matter of selection of the warmest available water, but instead relates to the higher seasonal abundance of age-2 red drum in spring and summer. Conversely, Adams and Tremain (2000) showed red drum abundances in the creek fluctuated seasonally and were highest during the winter and lowest during the summer months. Little information exists on distribution of sub adults within estuaries, although temperature-induced movements do occur between shallow and deep water (Matlock, 1990). My observations showed that red drum movement was highest in November, December, and January. Along the Texas coast, following a cold front where temperatures dropped to 4°C, beach seine catches by commercial fishermen in February 1974 increased (and larger fish were caught) when compared to catches prior to

December, indicating that a temperature response to red drum had occurred (Heffernan, 1973). Adams and Tremain (2000) observed higher abundances of red drum in Gator Creek, Georgia during the winter months and suggested that this may be due to increased habitat use of warmer creek waters when lagoon water temperatures decline. Conversely, the decrease in red drum abundance observed during the warmer months may represent the emigration of large fish from the creek during the summer.

All red drum in my study exhibited affinity to the northern regions of Bayou St. John. Dresser and Kneib (2007) showed that tagged red drum in an estuary in Georgia exhibited a persistent affinity to a particular site where a dock was located, especially during low and mid tides. The low-tide aggregation in the vicinity of the dock site seemed advantageous to red drum because the above-water structure of the floating dock acted as a cover for the fish. The dock site was abandoned by all individuals at varying time periods suggesting other habitats were used during flood tide. My red drum did not exhibit a release site preference but did show similar site affinities in the northern regions of the Bayou. The red drum may be exhibiting a form of aggregation behavior whereby they are drawn to others of their species. This could be triggered by spawning or feeding cues. Because red drum will not spawn in Bayou St. John (local salinities are too low), some of the larger animals (e.g., greater than four years of age) may be attempting to leave the Bayou to find spawning habitat.

Conclusions

Based on my research, I conclude that red drum can be successfully reintroduced into Bayou St. John as part of any fishery restoration management plan. Tagged red drum not only survived in the Bayou but the few recaptured fish also exhibited growth. Bachelier (2009)

observed red drum appear to tolerate a wide variety of environmental conditions, specific and consistent associations with various water quality, microhabitat, geographic, and prey variables in North Carolina, and in some instances, preferences for these factors differed between age-1 and age-2 red drum. Red drum in my study exhibited site fidelity to the northern regions of the Bayou, but not specific areas in the northern region. Data from the permanent YSIs showed that even though the rates of exchange were small, the northern regions of the Bayou experienced higher rates of tidal exchange than the southern regions. This could also mean that velocities are higher in the northern regions than the southern regions, causing an influx of forage organisms in these areas. Another study found that the distances sub-adult red drum (261- 385mm) move are small, and they normally remain within one estuary and are usually recaptured within 10 km of the tagging site, so they do not exhibit broad random movement (Matlock, 1990). Although the Bayou is approximately 6.5 km in length, the urbanized system provides ample area for red drum to move. Matlock's (1990) survey also mentions that sub-adult red drum are distributed throughout each estuary but their habitat preferences are unknown. My study did not show exact habitat preferences for red drum, however I did find that red drum preferred deeper and wider areas of the Bayou showing more physical preferences.

In addition to finding out how red drum survived in Bayou St. John, I also found that many local recreational fisherman and people that live on the Bayou are very interested in restoration efforts of the Bayou and turning it back into a nice recreational fishery once again. Local anglers want to increase water flow between Bayou St. John and Lake Pontchartrain so that the Bayou can exhibit increased water flow to flush the system out, allow for better water quality, and allow fish access into the Bayou. My results from this study will help determine the direction of future restoration efforts for Bayou St. John.

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Table 1. Release and recapture data for 29 red drum fitted with external acoustic radio transmitters and released into Bayou St. John in New Orleans. Asterisks indicate those 10 fish used as the focal red drum in the study. Red drum were either released at a common site in the northern region of the Bayou (Site A) or a site in the southern region (Site C). Data from the two recaptured fish include initial and final length and weight. Last heard date refers to the last ping date the fish was heard from active tracking. Tag retrieved indicates when transmitters that were shed from a fish early in the study were retrieved and then reused on a new fish.

| Fish # | Release | | | | Last Heard | Tag Retrieved | Recapture | | |
|--------|---------|-------|------|------|------------------------------------|-----------------|-----------|-------|------|
| | Date | SL mm | Wt g | Site | | | Date | SL mm | Wt g |
| 1 | 5/31/07 | 490 | 2080 | A | 1/25/08 | | | | |
| *2 | 5/31/07 | 552 | 2810 | A | 5/29/08 | | | | |
| *3 | 5/31/07 | 517 | 2310 | A | 5/29/08 | | | | |
| 4 | 5/31/07 | 540 | 2690 | A | 10/3/07 | 10/15/07 | | | |
| 5 | 10/5/07 | 584 | 2070 | A | 10/26/07 | | | | |
| 6 | 4/13/07 | 510 | 2490 | A | 8/17/07 | | | | |
| *7 | 5/31/07 | 530 | 2630 | A | 5/29/08 | | | | |
| 8 | 5/31/07 | 554 | 2310 | A | 4/15/08 | | | | |
| *9 | 4/13/07 | 540 | 2730 | A | 5/29/08 | | | | |
| 10 | 5/31/07 | 540 | 2330 | A | 7/25/07 | | | | |
| *11 | 5/31/07 | 545 | 3030 | A | 5/1/08 | | | | |
| 12 | | | | | transmitter malfunction/never used | | | | |
| 13 | 10/5/06 | 515 | 1740 | A | 5/1/08 | | | | |
| *14 | 5/31/07 | 530 | 2670 | A | 5/29/08 | | | | |
| *15 | 4/13/07 | 500 | 2220 | A | 5/29/08 | | 12/14/09 | 551 | 2220 |
| 16 | 5/31/07 | 525 | 1940 | A | 10/3/07 | 10/15/07 | | | |
| 17 | 4/13/07 | 530 | 2590 | A | 5/1/08 | | 12/14/09 | 575 | 2670 |
| 18 | 4/13/07 | 570 | 3570 | A | 5/1/08 | | | | |
| 19 | 10/5/06 | 515 | 1860 | A | 4/15/08 | failed attempts | | | |
| *20 | 4/13/07 | 540 | 2670 | A | 5/1/08 | | | | |
| 21 | 5/31/07 | 528 | 2019 | A | 10/3/07 | 10/15/07 | | | |
| *22 | 10/5/06 | 585 | 2070 | A | 5/29/08 | | | | |
| 23 | 5/2/07 | 542 | 2550 | A | 3/14/08 | | | | |
| 24 | 4/13/07 | 550 | 3090 | A | 3/14/08 | | | | |
| 25 | 4/13/07 | 545 | 2800 | A | 12/12/07 | | | | |
| *26 | 5/31/07 | 515 | 2540 | A | 5/1/08 | | | | |
| 27 | 10/5/06 | 520 | 1890 | A | 5/29/08 | | | | |
| 28 | 11/1/07 | 501 | 2460 | C | 1/15/08 | new fish | | | |
| 29 | 11/1/07 | 514 | 2400 | C | 12/12/07 | new fish | | | |
| 30 | 11/1/07 | 552 | 2790 | C | 5/29/08 | new fish | | | |

Table 2. Recapture efforts for 29 red drum tagged and released into Bayou St. John, New Orleans. The only successful recaptures were on 14 December 2007. A recreational angler recaptured one fish 3 weeks after its release on 24 February 2009, however, no useful data were obtained from the angler.

| Date | Gear Type | Locality | Number of gill net sets | Catch |
|-------------|------------------|--------------------------|-------------------------|-------|
| 3 Nov 2007 | hook and line | northern Bayou regions | | 0 |
| 14 Dec 2007 | hook and line | between flood structures | | 4 |
| 14 Apr 2008 | hook and line | northern Bayou regions | | 0 |
| 1 May 2008 | gill net | northern Bayou regions | 4 | 0 |
| 1 May 2008 | hook and line | northern Bayou regions | | 0 |
| 15 May 2008 | gill net | northern Bayou regions | 5 | 0 |
| 15 May 2008 | hook and line | northern Bayou regions | | 0 |
| 29 May 2008 | gill net | northern Bayou regions | 5 | 0 |
| 29 May 2008 | hook and line | northern Bayou regions | | 0 |
| 3 July 2008 | electro-shocking | northern Bayou regions | | 0 |
| 3 July 2008 | gill net | between flood structures | 4 | 0 |

Table 3. Growth and gut content data from four red drum recaptured on 14 December 2007. Two of these red drum were not identifiable due to shed transmitters, though scars on the dorsal musculature indicated that they had been tagged previously during the study.

| Fish # | Initial Release Date | Recapture Date | Initial SL | Final SL | Initial weight | Final weight | Gut Content |
|--------|----------------------|----------------|------------|----------|----------------|--------------|-------------------|
| #1 | 5/31/2007 | 12/14/2007 | 490 | 520 | 2080 | 2340 | empty |
| n/a | n/a | 12/14/2007 | n/a | 545 | n/a | 2810 | empty |
| #17 | 4/13/2007 | 12/14/2007 | 530 | 575 | 2670 | 3200 | empty |
| n/a | n/a | 12/14/2007 | n/a | 520 | n/a | 2100 | <i>C. sapidus</i> |

Table 4. Data for a second group of 19 red drum reintroduced into Bayou St. John and tagged with internal transmitters for use with a remote tracking system. Fish were released on different dates and at different sites. Fish #17 (*) was recaptured by a recreational angler 3 weeks after its release, however no useful data were obtained from the angler.

| Fish # | Date | Weight g | SL mm | Site |
|--------|------------|----------|-------|------|
| 1 | 10/22/2008 | 3625 | 590 | B |
| 2 | 11/14/2008 | 4000 | 614 | B |
| 3 | 11/14/2008 | 2675 | 522 | B |
| 4 | 11/14/2008 | 2750 | 530 | B |
| 5 | 11/24/2008 | 2300 | 510 | B |
| 6 | 11/26/2008 | 2700 | 530 | B |
| 7 | 11/26/2008 | 2900 | 537 | B |
| 8 | 11/26/2008 | 3175 | 544 | B |
| 9 | 11/26/2008 | 4340 | 635 | B |
| 10 | 11/26/2008 | 2650 | 503 | B |
| 11 | 11/26/2008 | 2640 | 515 | B |
| 12 | 2/24/2008 | 3270 | 555 | C |
| 13 | 2/24/2008 | 3120 | 555 | C |
| 14 | 2/24/2008 | 3120 | 548 | C |
| 15 | 2/24/2008 | 3870 | 550 | C |
| 16 | 2/24/2008 | 3600 | 557 | C |
| *17 | 2/24/2008 | 3030 | 530 | C |
| 18 | 2/24/2008 | 3330 | 540 | C |
| 19 | 2/24/2008 | 2940 | 525 | C |

Table 5. Locations of receivers throughout the study period. Receivers were initially deployed on 14 October 2008. Two receivers were moved throughout the study to better determine locations of fish.

| Buoy # | <u>Date</u> | | Location |
|--------|-------------|-------------|---|
| | Deployed | Moved | |
| 1-a | 14 Oct 2008 | | inside flood control structure |
| | 14 Oct 2008 | | |
| 2-a | 14 Oct 2008 | | between Robert E. Lee and Filmore Bridges |
| 3-a | 14 Oct 2008 | | island |
| 4-a | 14 Oct 2008 | | I-610 Bridge |
| 1-b | | 24 Feb 2009 | island |
| 3-b | | 21 Nov 2008 | outside flood control structure |
| 3-c | | 1 May 2009 | Cabrini Bridge |



Figure 1. Aerial image of Bayou St. John, New Orleans, Louisiana. Buoy numbers show locations of remote receivers. Red drum were released at sites A, B, and C on different dates throughout the study.



Figure 2. Aerial image of the north end of Bayou St. John from 1947 showing its connection to Lake Pontchartrain. The image illustrates how the Bayou looked before the banks were developed, impounded, and closed off from the Lake and also shows its previous accessibility to estuarine fishes such as red drum and spotted seatrout. Image modified from http://www.thepastwhispers.com/Old_New_Orleans.html.



Figure 3. Images of the old flood-control structure or “waterfall dam” constructed in 1962 at the northern end of Bayou St. John. This structure prevented most adult estuarine dependent fishes from accessing the Bayou and impedes water flow between the two systems. Images modified from www.saveourlake.org.



Figure 4. Aerial view of both flood control structures on the northern end of Bayou St. John near Lake Pontchartrain. The old structure or “waterfall dam” was built in the 1960s and prevents estuarine fishes from accessing the Bayou and impedes water flow between the two systems. The new structure or “sluice gates” was built in the 1980s and allows limited water exchange and small aquatic organisms between the two systems through a mesh wall located under the structure.



Figure 5. Image of a red drum fitted with an external Acoustic Radio Transmitter, ART-01. These transmitters (length = 105 mm, weight = 12 g) were attached using stainless steel wire inserted through two points in the dorsal musculature below the dorsal fin. The initial group of 29 reintroduced red drum tagged with these transmitters were released into the Bayou on different dates from October 2006 to November 2007.

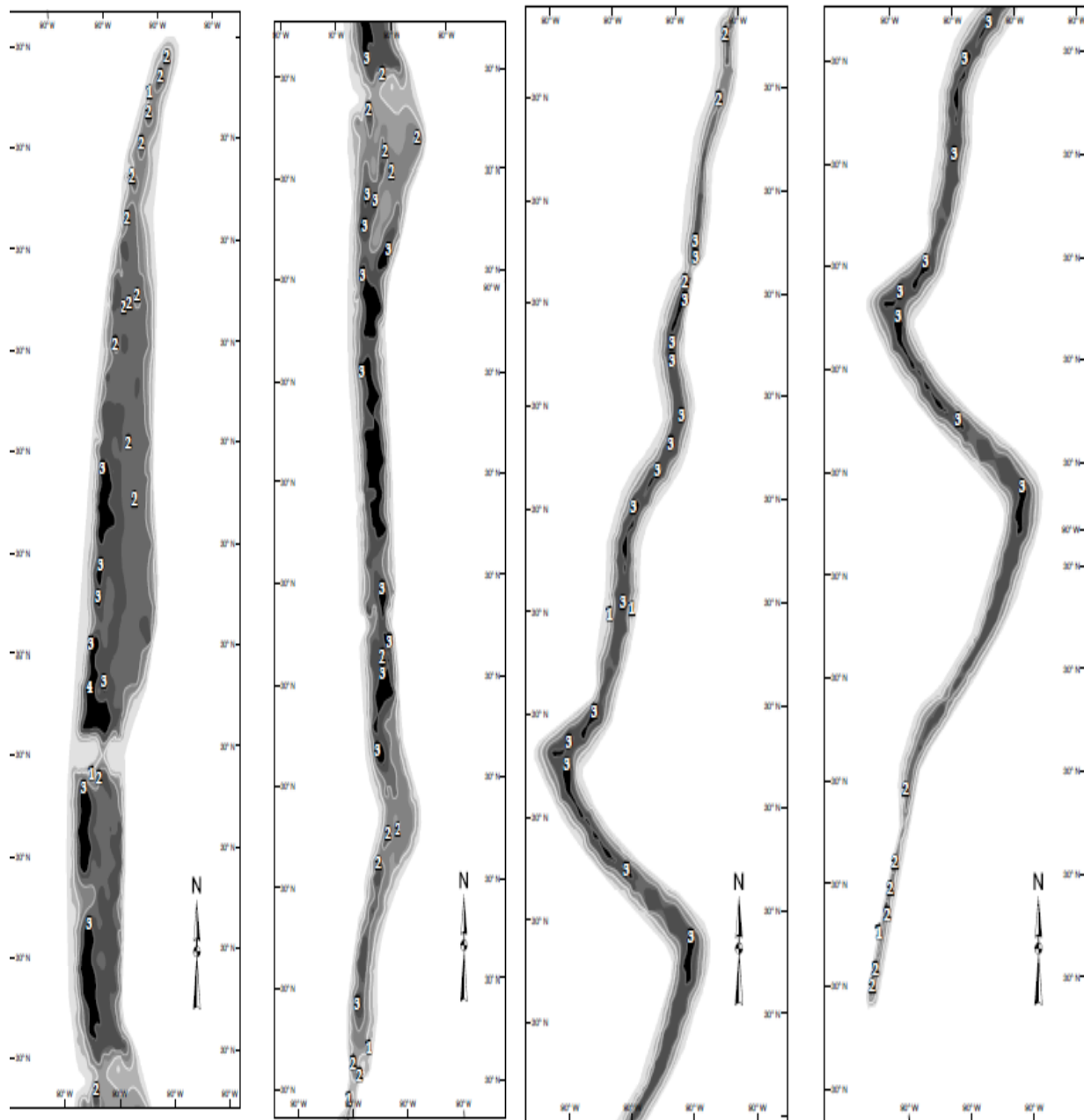


Figure 6. Bathymetry maps of four regions of Bayou St. John as measured in summer 2008. All depths are in meters. The far left map represents the northernmost region of the Bayou and ranges from Robert E. Lee Boulevard to Mirabeau Boulevard. Most tracked red drum occurred in this region. The second map represents the region from Mirabeau Boulevard to Highway I-610 Bridge (release site B). The third map represents the region from Highway I-610 Bridge to Dumaine Street and the fourth map represents the southernmost region. Note how northern regions typically exhibit deeper and wider habitats.

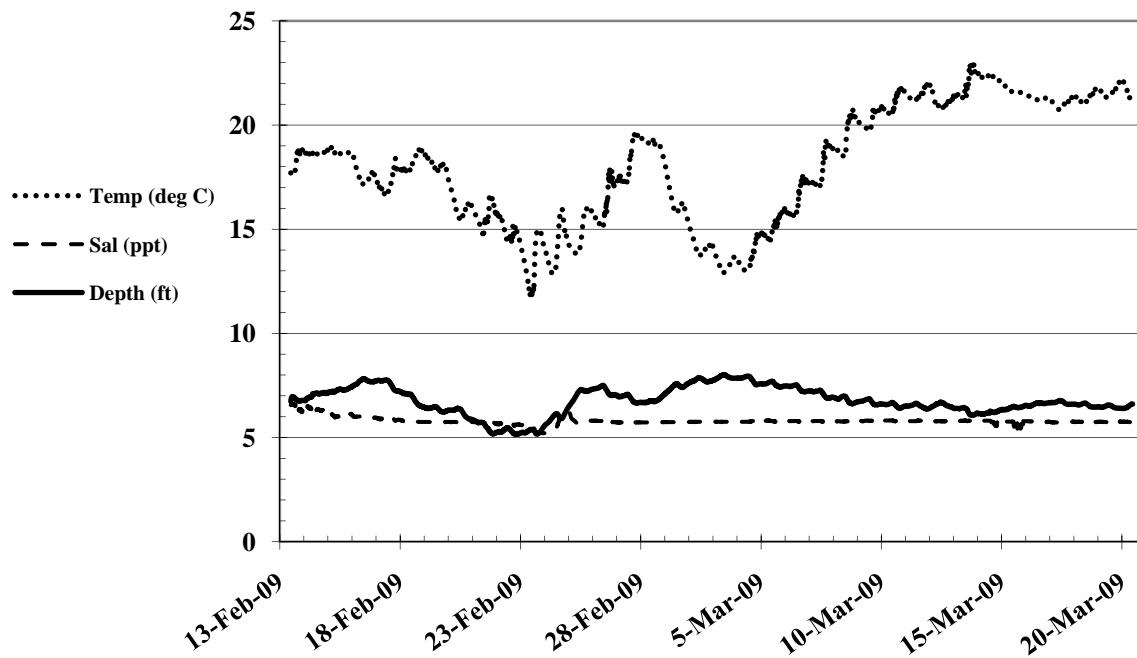


Figure 7. Environmental data collected from the northern region of Bayou St. John between 13 February and 20 March 2009. Data were measured by permanent YSI meters deployed in the Bayou for the collection of constant water quality data. During this time, water temperatures exhibited the most variability with smaller changes occurring in depth and salinity.



Figure 8. Images of surgery procedure for placing internal transmitters in red drum. Left: red drum on surgery table during surgery. Maintenance bath water is lightly pumped into the mouth to maintain sedation and oxygen while inserting a transmitter into the peritoneal cavity. Right: Red drum surgery table with red drum in maintenance bath to continue level of sedation.

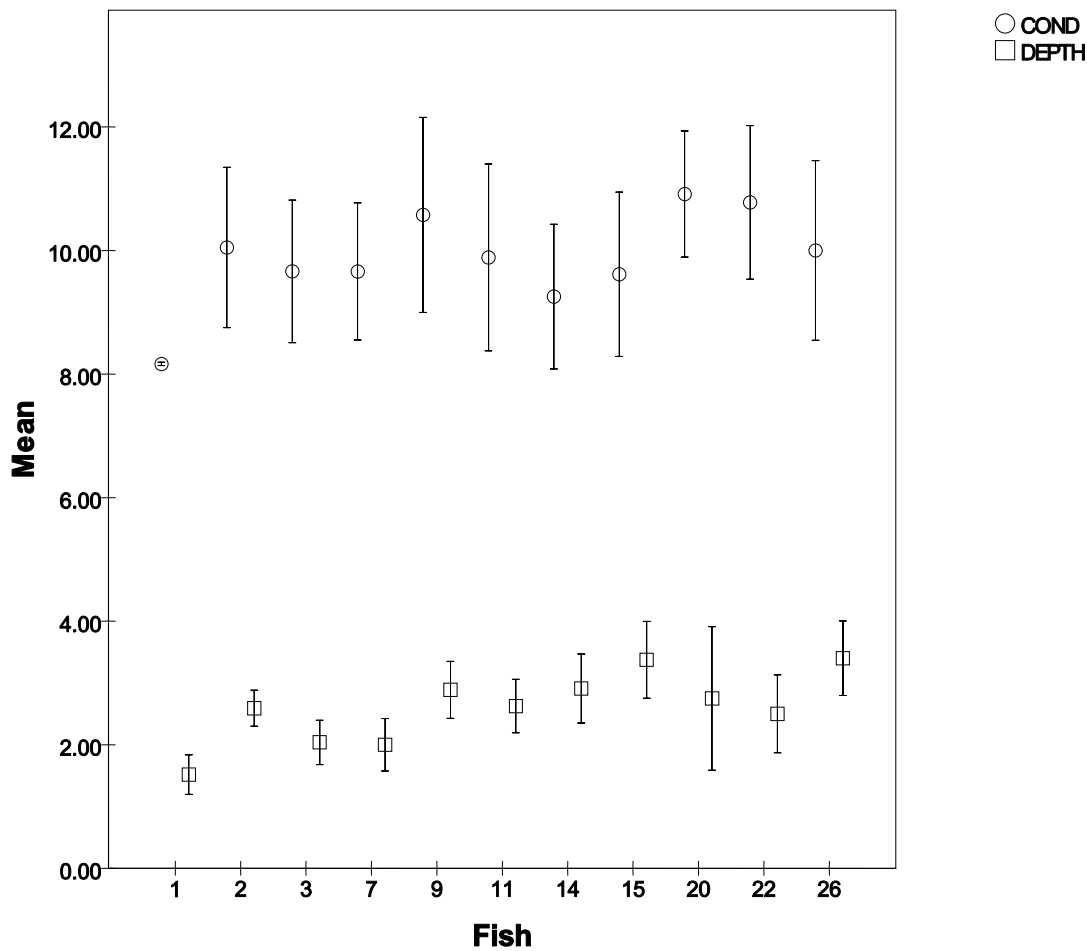


Figure 9. Mean conductivity and depth (with 95% confidence intervals) as measured at localities for ten red drum reintroduced into Bayou St. John. Fish #1 represents measurements taken at random points over the same time period (June 2007 to October 2008). Based on MANOVA (with Bonferroni post hoc tests) conductivity and depth were found to be significantly different among some red drum habitats and random points within the Bayou ($p < 0.05$). There were also significant differences in depth among red fish, with fish 3 occurring in significantly shallower depths than fish 15 and 26 (Bonferroni, $p = 0.005$ and 0.001 , respectively). Fish 7 also occurred in significantly shallower depths when compared to fish 15 and 26 (Bonferroni, $p = 0.006$ and 0.002 , respectively).

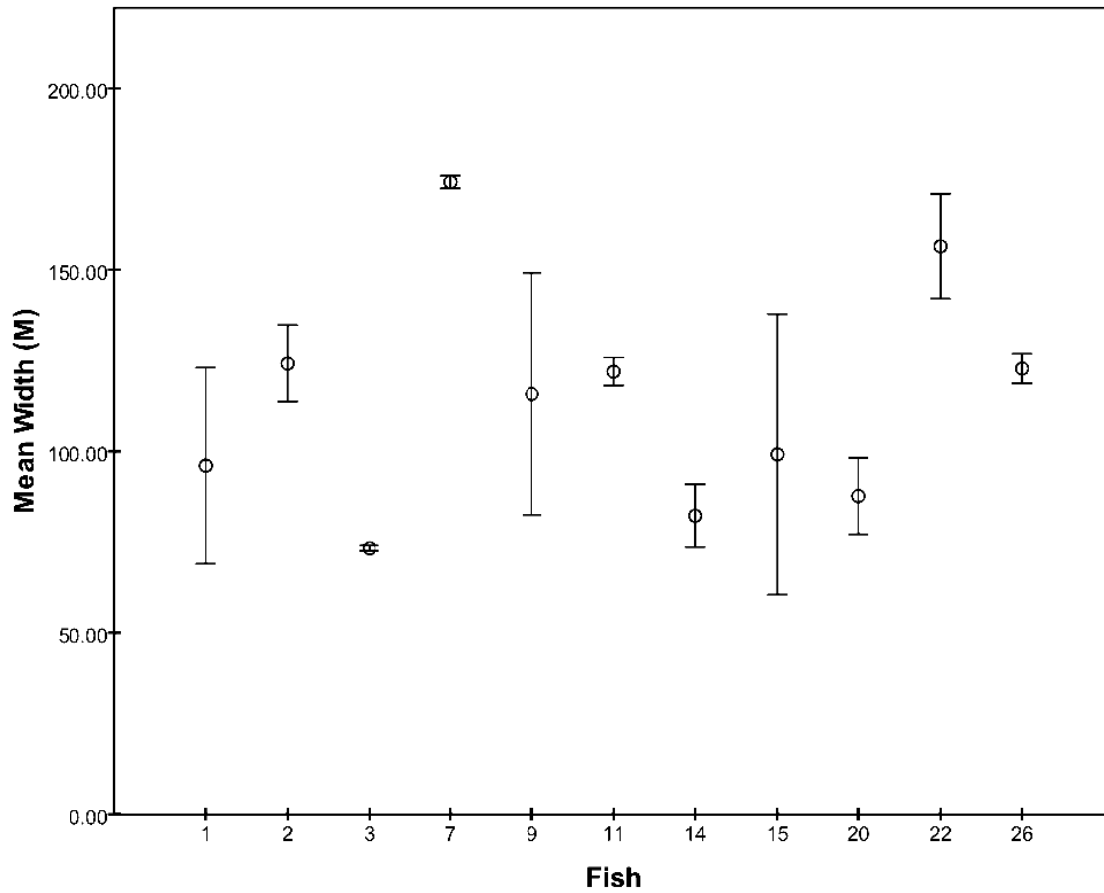


Figure 10. Mean width (with 95% confidence intervals) of Bayou St. John as measured at localities for ten reintroduced red drum. Fish #1 represents measurements taken at random points over the same time period (June 2007 to October 2008). Note that Fish 7 and Fish 22 occurred in significantly wider areas of the Bayou compared to random points (MANOVA, $p < 0.01$).

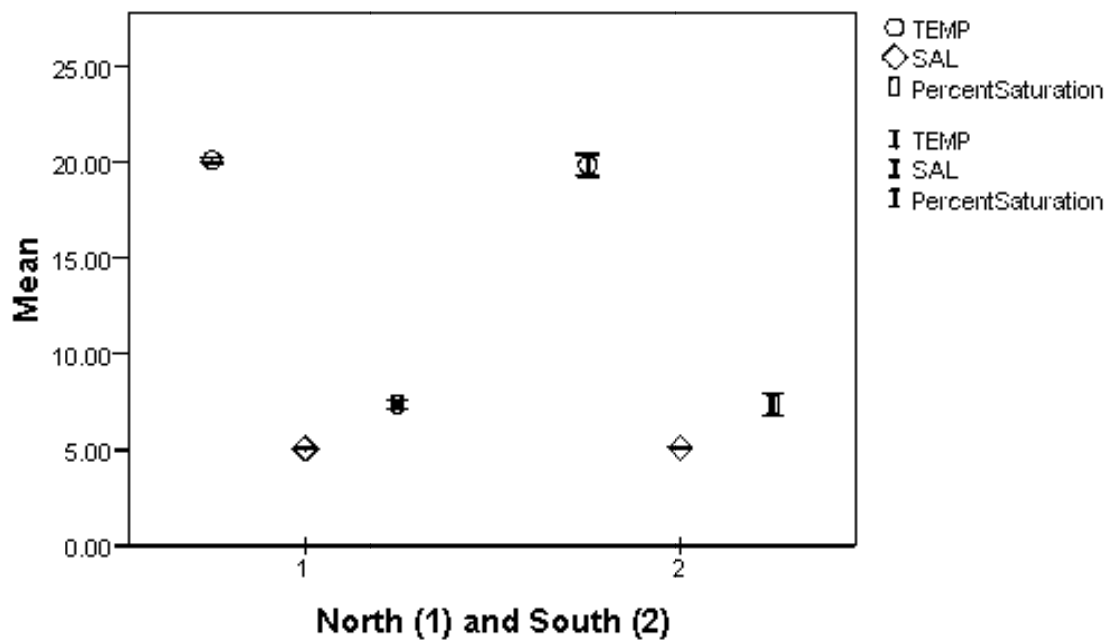


Figure 11. Mean temperature, salinity, and percent saturation of oxygen (with 95% confidence intervals) as measured at 20 random sites in both the northern and southern regions of Bayou St. John, New Orleans. Two-sample Kolmogorov-Smirnov tests showed no significant differences in environmental variables between the north and south regions ($p > 0.05$).

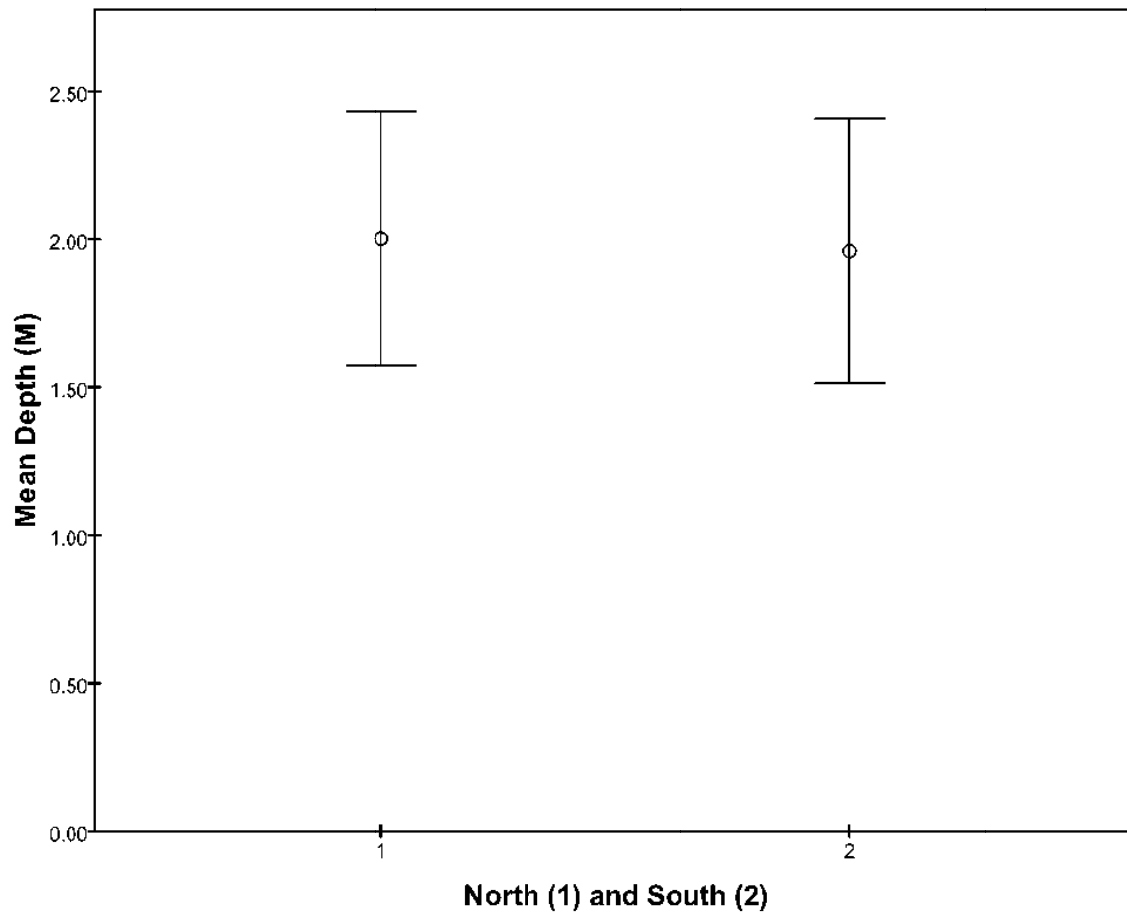


Figure 12. Mean depth (with 95% confidence intervals) as measured at 20 random sites in both the northern and southern regions of Bayou St. John, New Orleans. There were no significant differences (two-sample Kolmogorov-Smirnov test; $p = 0.978$) in depth between the north and south regions, though the northern regions are slightly deeper than the southern regions.

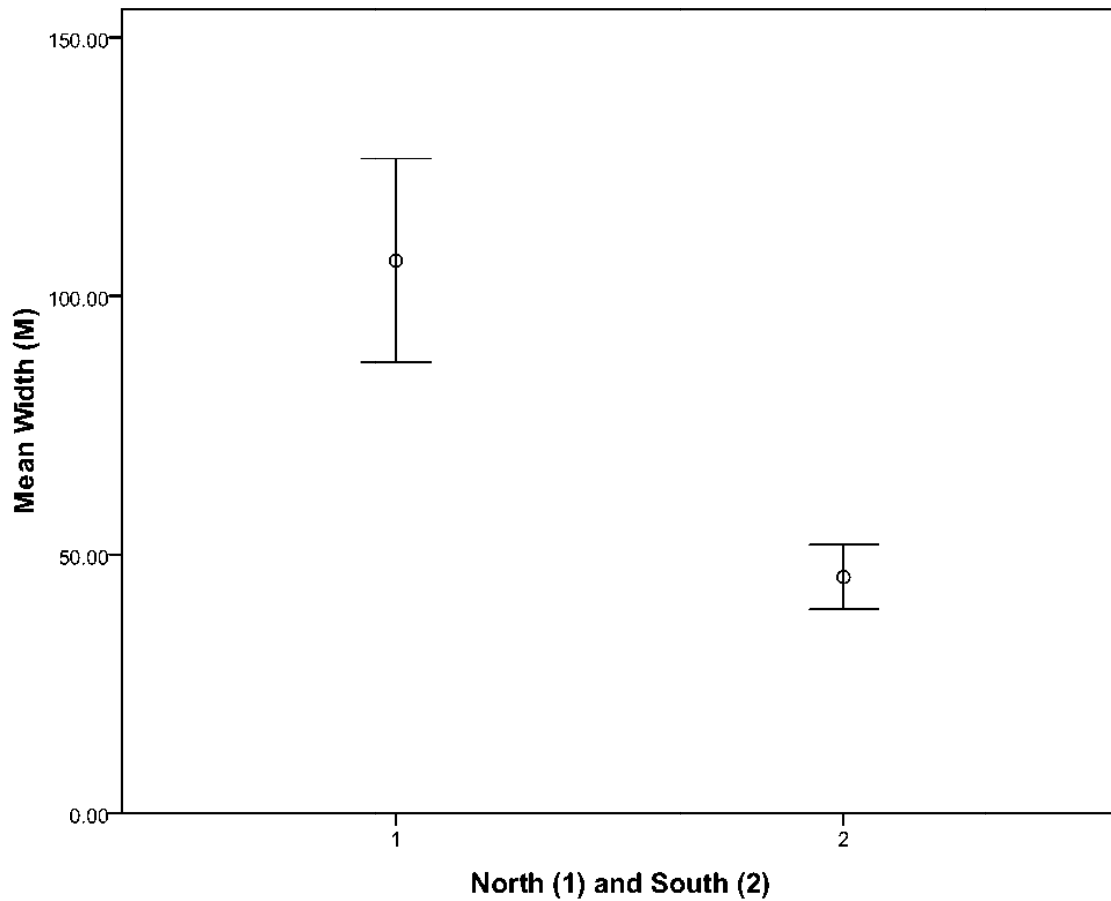
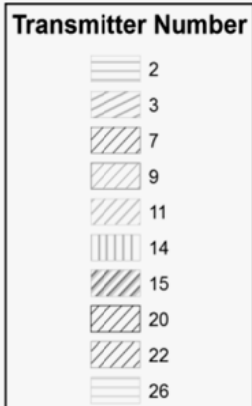


Figure 13. Mean stream width (with 95% confidence intervals) as measured at 20 random sites in both the northern and southern regions of Bayou St. John, New Orleans. There were significant differences (two-sample Kolmogorov-Smirnov test; $p = 0.000$) in width between the north and south regions confirming that the northern region is wider in areas than the southern region.

Bayou St. John Redfish Study Home Range Areas



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0 110 220 440 660 880 1,100 Meters



Figure 14. Map of red drum home ranges in the northern region of Bayou St. John. Home ranges were determined by tracking and GPS coordinates were entered into ArcMap where polygons were constructed. Note the higher concentration of red drum and over-lapping home ranges in the more northern portions and more isolated home ranges toward the south.



Figure 15. Images of gut contents from red drum recaptured on 14 December 2007. Out of the four recaptured red drum, three stomachs were empty (left) and one contained a small blue crab (right).

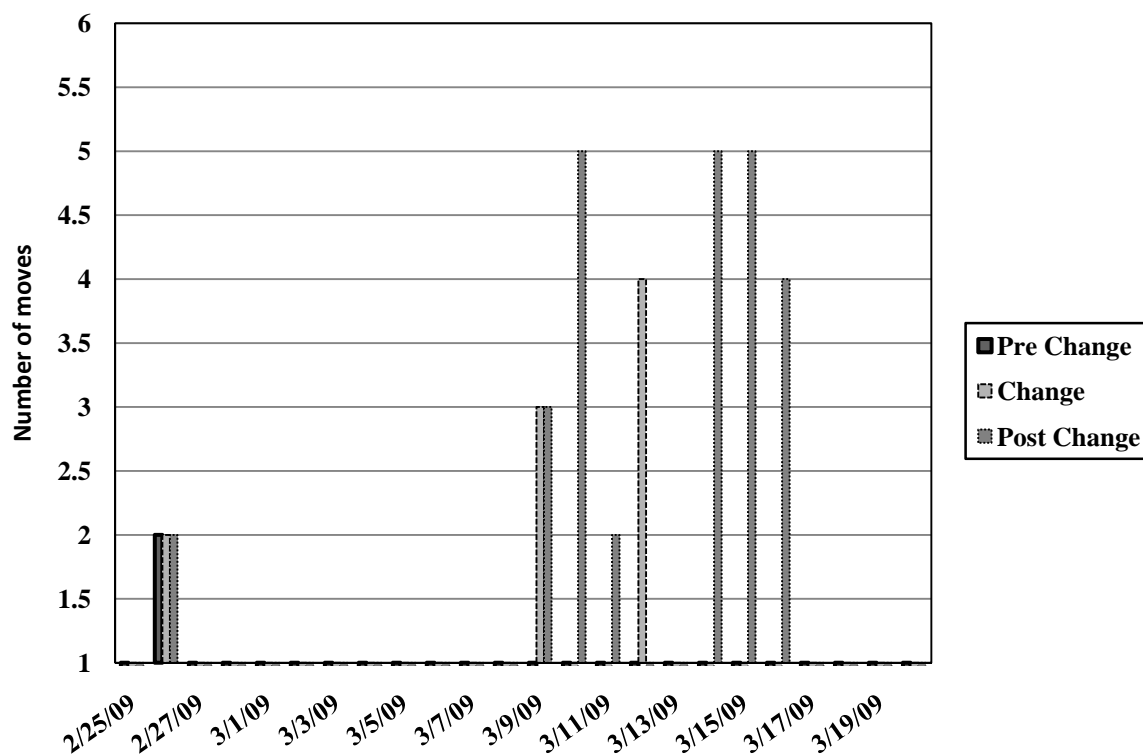


Figure 16. Number of moves between receivers by fish #12 during the focal month period. Periods of changing temperatures were classified as pre-change, during change and post change to determine if red drum exhibited an increase of activity during these changes. Red drum #12 exhibited more movement than any other of the 18 red drum during this focal period of 13 February to 20 March 2009.

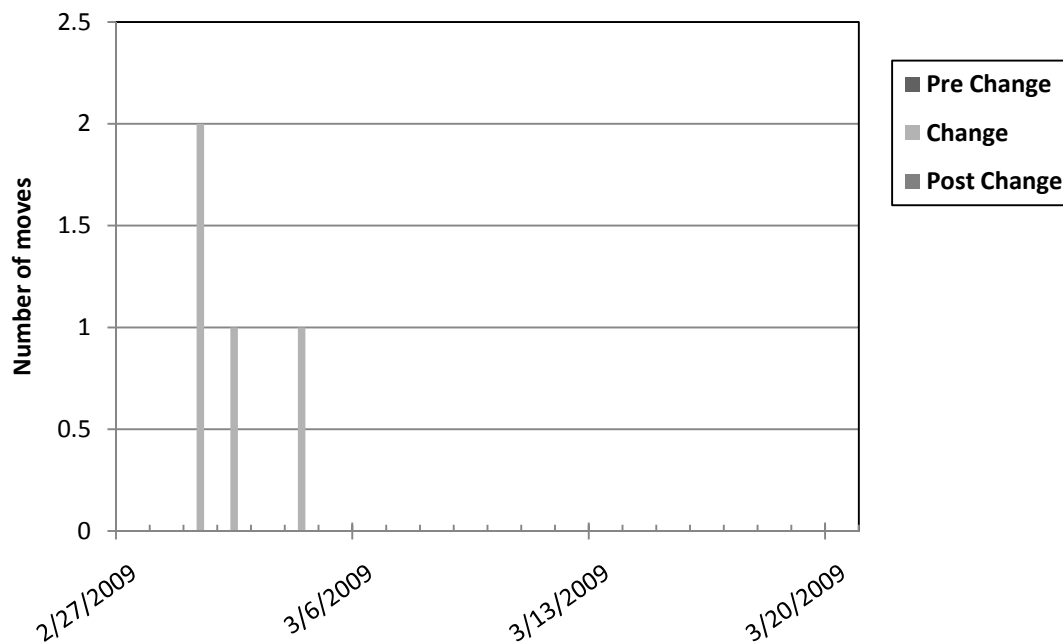


Figure 17. Number of moves between receivers by fish #15 during the focal month period. Periods of changing temperatures were classified as pre-change, during change and post change to determine if red drum exhibited an increase of activity during these changes. Fish #15 experienced an increase of activity with changing temperatures when first introduced into Bayou St. John. However, this increase in movement probably coincided with initial release into Bayou St. John as most fish exhibited an increase in activity when first introduced before settling down. This is the only movement exhibited by this fish during the entire focal period.

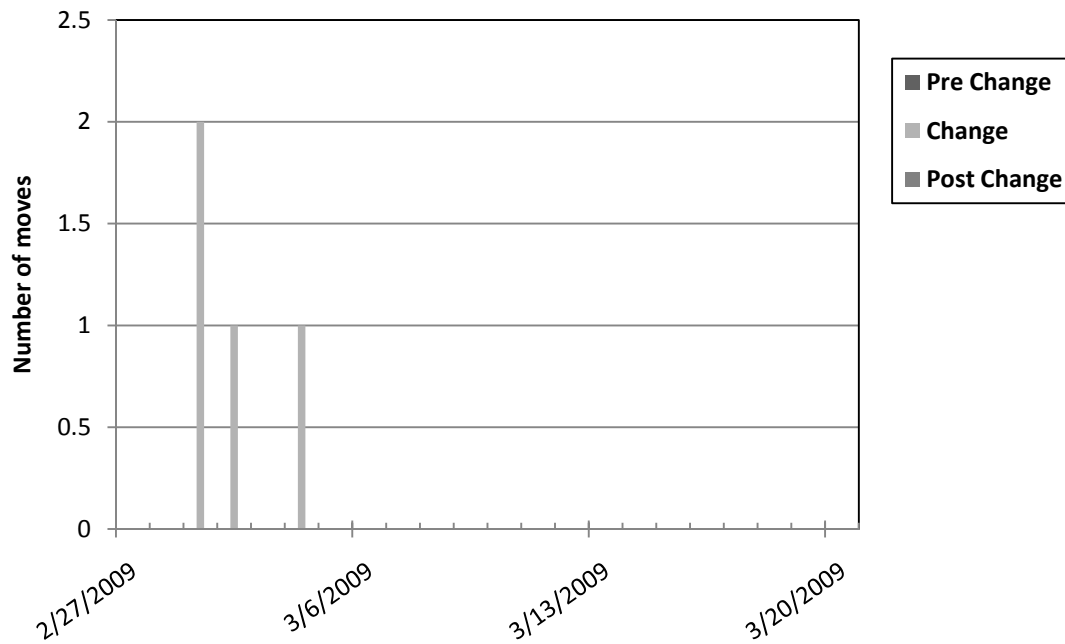


Figure 18. Number of moves between receivers by fish #15 during the focal month period. Periods of changing water levels were classified as pre-change, during change and post change to determine if red drum exhibited an increase of activity during these changes. Fish #15 experienced an increase of activity with changing water levels when first introduced into Bayou St. John. However, this increase in movement probably coincided with initial release into Bayou St. John as most fish exhibited an increase in activity when first introduced before settling down. This is the only movement exhibited by this fish during the entire focal period.

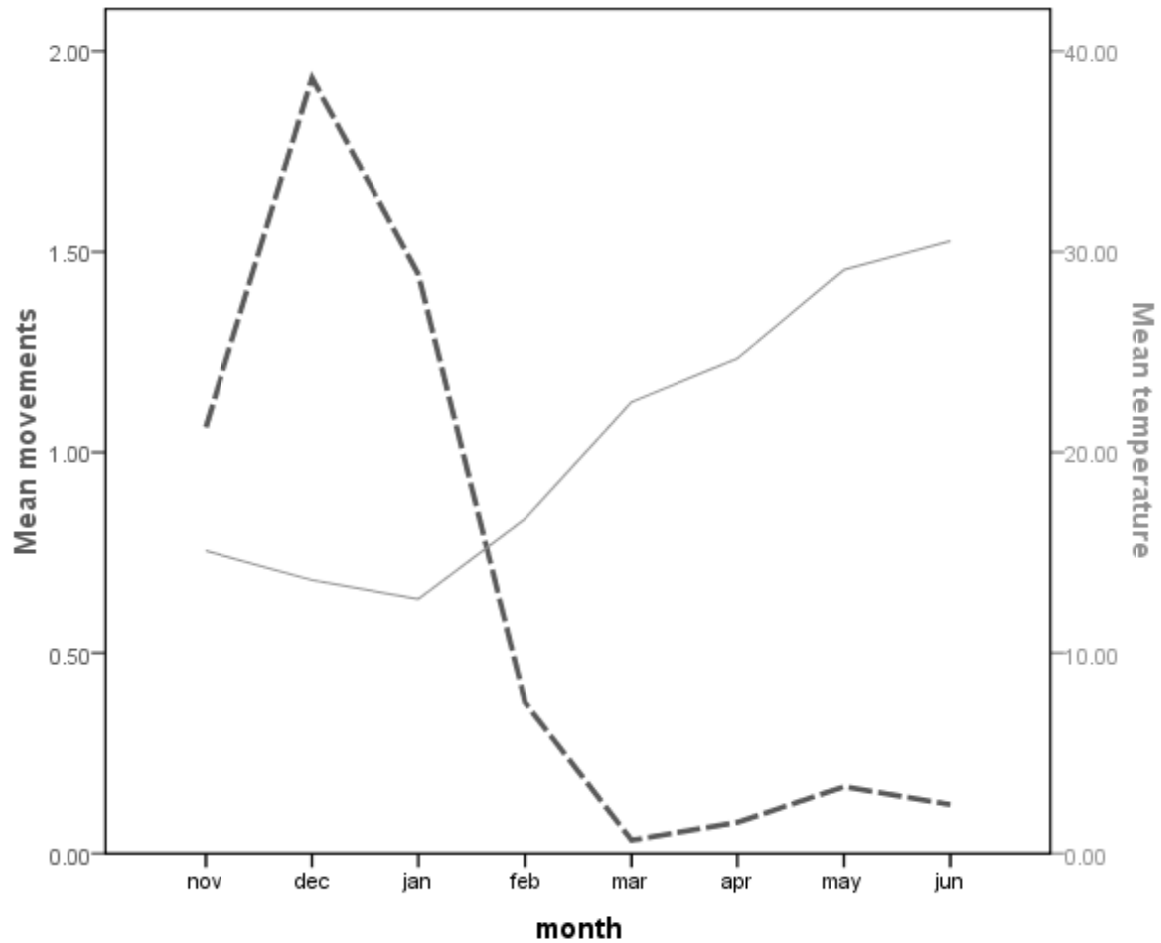


Figure 19: Average daily movements for 19 red drum reintroduced into Bayou St. John, New Orleans compared to mean water temperature over the same period. Movements were highest in December 2008 and then decreased to the lowest level in March 2009. As water temperature decreased from November to January, red drum movement remained high. As water temperatures increased from January to June, though, movements decreased to a low in March and then remained relatively low. For water temperature, there were significant differences among all months except December and January (Repeated Measures ANOVA, overall $p < 0.001$).

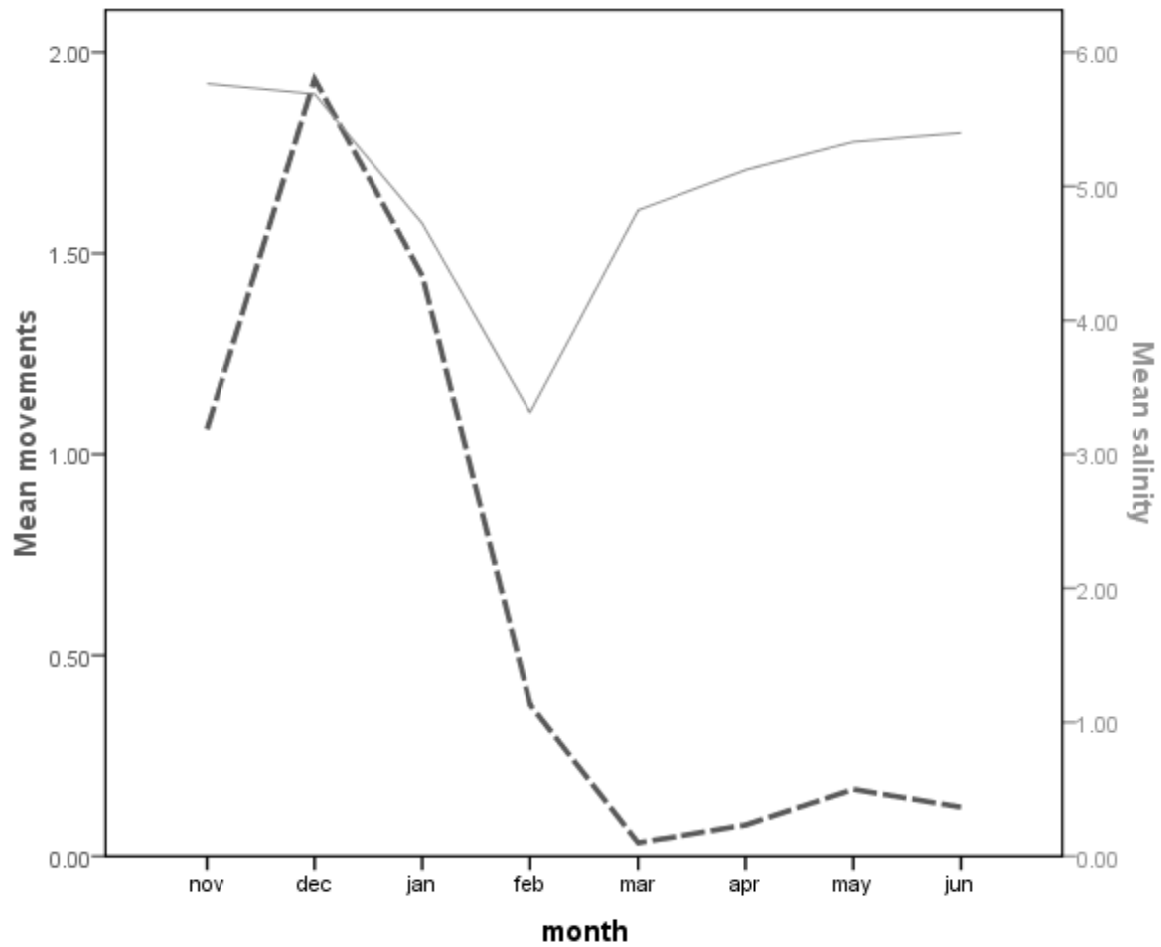


Figure 20: Average daily movements for 19 red drum reintroduced into Bayou St. John, New Orleans compared to mean salinity (psu) over the same period. The number of movement was highest in December 2008 and then decreased to the lowest level in March 2009. This pattern appears unrelated to the movement of the red drum.

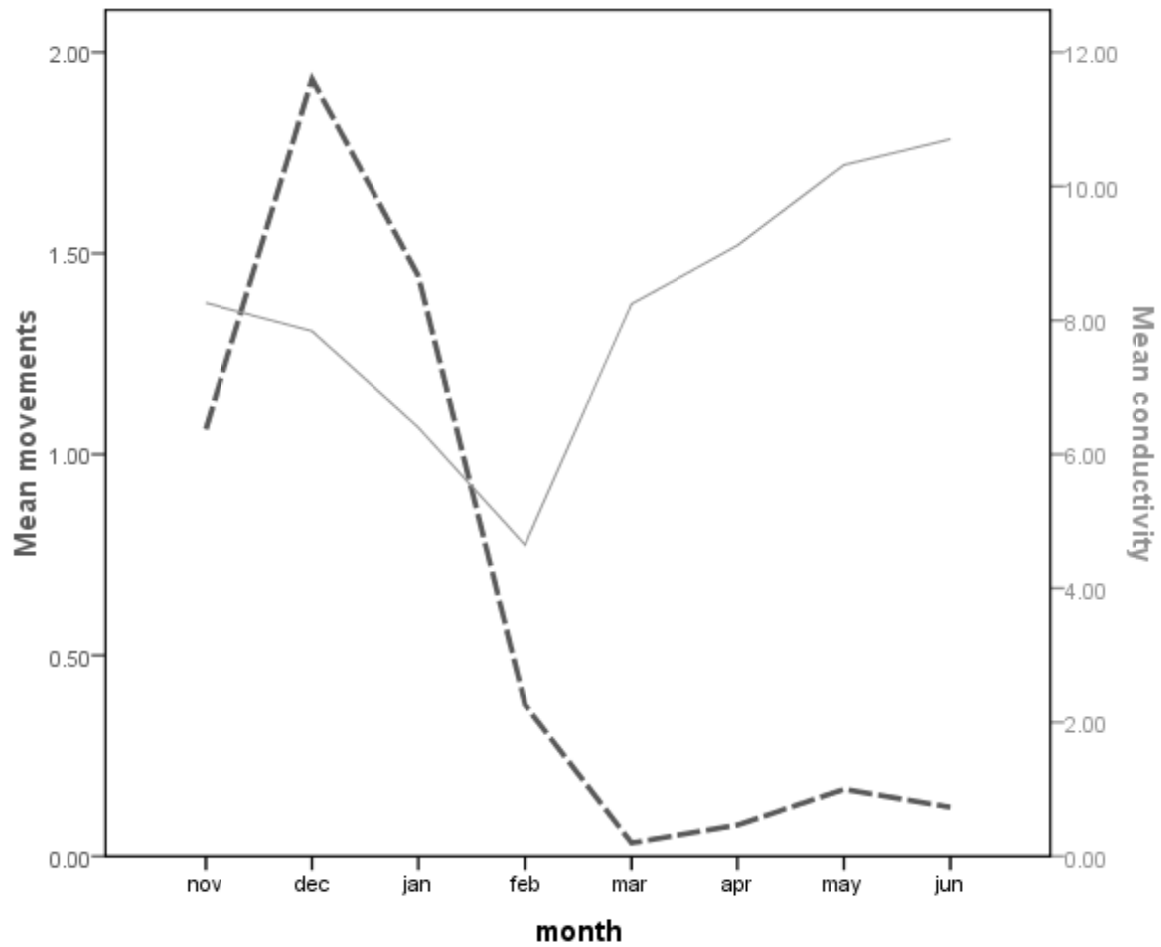


Figure 21: Average daily movements for 19 red drum reintroduced into Bayou St. John, New Orleans compared to mean conductivity over the same period. The number of movement was highest in December 2008 and then decreased to the lowest level in March 2009. This pattern appears unrelated to the movement of the red drum.

Vita

Sunny Justina Brogan was born October 22, 1978, in Baton Rouge, Louisiana. Her parents, Sonny and Lani Brogan, raised her along with her older sisters, Tonia and Tikki in St. Amant, Louisiana. Sunny spent most of her adolescent life outdoors catching crawfish in the ditches, riding 4-wheelers in the woods and under the hoods of muscle cars with her Dad. Sunny received her Bachelor's degree in Science from Southeastern Louisiana University in 2003. Two weeks after graduating college, Sunny headed up to Arkansas where she spent six months assisting graduate students with field work in freshwater streams. This was when she realized she had a passion for working in aquatic environments and studying fish. Sunny married her husband, Jason, in 2005 and promises to give him children one day.