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CRAYFISH HARVESTING PRACTICES IN THE SOUTHERN ATCHAFALAYA RIVER
BASIN: QUANTITATIVE AND QUALITATIVE ASSESSMENT OF HARVESTER
TECHNIQUES AND HYDROLOGIC CONNECTIVITY INFLUENCE ON HARVESTING
STRATEGIES

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The School of Renewable Natural Resources

by
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B.S., Escuela Agrícola Panamericana Zamorano, 2011
May 2018
ACKNOWLEDGEMENTS

Continuing my academic career has been one of the most important decisions in my life, and the only way to accomplish it has been with the support of many people. First and for sure the most important I want to thank God because He has never abandoned me. To my lovely wife, who accepted to do this journey with me, and has been my best friend, partner, and colleague along each step of this project.

My eternal thanks to Dr. William Richardson, who provided me the opportunity to come to LSU to get this degree, and to Mrs. Susan Karimiha for all the logistic support. Also, I want to thank my adviser Dr. Michael Kaller for being an extremely awesome boss, professor, and mentor. Thank you so much for introducing me to the science world, and share with me your knowledge and experience.

I would like to thank my committee members, Dr. William Kelso, and Dr. Richard Keim for their wise advice, accurate comments, and permanent suggestions. To Raynie Harlan and Tiffany Pasco for their constant help and support. Thanks to all people who worked with me, especially Savannah Morales for her infinite patience. Also, I would like to thank Tyler Loeb, Jackie, Keyla, Colleen, Rene, Corinne, Kristy, Samantha, Kamela, Erin, William, Catherine, and Jacob.

Finally, I would like to thank my mother Rosemary De Vargas and my father Luis Vargas who has been helping from the distance with support words since the first day. To my best friends, my older brother Luis Vargas Jr. whose steps I am following, and my younger brother Isaac Vargas for his unconditional help.
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ABSTRACT

Fisheries produce important impacts around the world through the exploitation of a wide range of species. In Louisiana, crayfish is the most emblematic crustacean and supports a multi-million industry based on pond culture and harvest from natural habitats. Although the economic value (USD) of wild-harvested crayfish has decreased from 10% to 3% of total crayfish value from 2013 to 2015, wild harvested crayfish are highly desired by many consumers and have a strong socio-cultural importance in Louisiana and other Gulf of Mexico coastal regions. This project evaluated harvesting practices by: 1) field observation and mapping of harvest sites in southwestern Atchafalaya River Basin; and 2) directed interviews with individual harvesters. Field observations included trap locations, water quality, habitat components, and fishery independent sampling. Weekly field observations were conducted along four transects across a gradient of water quality over two harvesting seasons (2015 and 2016). I also assessed floodplain connectivity with river water sources by conservative tracers sampled at each water quality site biweekly during 2016. Directed interviews of 23 harvesters provided data on fishing strategies, factors used to decide when to start fishing, and selection of harvesting locations. Trap density was first assessed for spatial autocorrelation by Pearson Chi-Square Quadrat Test and Nearest Neighbor Tests and then by generalized linear models including water quality, habitat, harvester answers and conservative tracers. Analyses demonstrated that trap locations were not random, i.e., traps were set in relatively clear water (NTU < 69.4) in in depths from 1-3 m or 3-3.6 m. Very few traps were set high turbidity water regardless of depth. Trap density was positively associated with river water inputs, based on conservative tracer results. Harvester interviews corroborated the importance of tradition (35% - 47%) and depth (88%) when starting harvesting and setting traps. Additionally, harvesters (> 40%) considered water color (likely a surrogate for turbidity) important for trap locations. Although harvesters may not be using water
quality and chemistry data, their harvesting practices do follow water movements, likely based on accumulated experience with depth, flow velocity and turbidity.
CHAPTER 1
GENERAL INTRODUCTION

The appearance of mankind on earth is a subject full of myths and theories. However, undoubtedly, the human race has been a species able to adapt its own behavior, and environment to satisfy its own needs. One of the most important needs that all living organisms have to satisfy is the food resource. According to Maslow (1943) in "A Theory of Human Motivation", the source of food is included in the group of the 'physiological' needs, which are the most important of all needs. To supply this need, humans have evolved through millions of years. Such evolution is a constant process influenced by natural changes, to provide adaptations to the environment.

To address this important physiological need, fishing activities played an important role for early civilizations (Richards and Trinkhaus 2009; Yaowu et al. 2009) and, at present, fishing is an important activity that represents a source of food and nutrition for many people that depend on the healthy proteins and nutrients that seafood supplies (Bach-Faig et al. 2010). Additionally, the impact on the economy through the creation of jobs, and local and international trading of products is extremely important for countries around the world. During 2010, capture fisheries and aquaculture accounted a total commercial value of U.S. $217.5 billion. By 2014, the world per capita supply of fish was 20 Kg, and 56.6 million people were engage in the primary sector of fisheries and aquaculture (FAO 2012, 2016).

The fisheries industry in the United States (U.S.) is composed of wild harvest and aquaculture activities, exploiting a wide range of species, habitats and products (FAO 2016). Among all products included in the U.S. fisheries industry, crayfish is the most emblematic one for the State of Louisiana. As the “crawfish state”, Louisiana has the largest industry in the United States. Historical and social events have been responsible for the opening and subsequent development of the consumption of crayfish as a source of food.
Crayfishes are members of the order Decapoda. This order includes crabs, lobsters and shrimps. Globally, there are over 640 species, of which around 77% of these species occur in North America. North American species are composed by members of the families Astacidae and Cambaridae, and, in Louisiana, 39 species have been identified (Taylor 2007, Crandall and Buhay 2008, Walls 2009). Crayfishes are adapted to diverse habitats conditions, and can live in burrows (isolated or connected from the water table), streams, lakes, large rivers, and caves (Crandall and Buhay 2008). Crayfishes play an important role in their ecosystems. As omnivorous organisms and well adapted to different freshwater habitats, crayfishes occupy a central place in the trophic web, functioning as bioprocessors of detritus, predators of small organisms, and as a source of food for fishes, birds, reptiles, and mammals (Hobbs 1975; Hobbs 1993; Lodge et al. 1994; Allert et al. 2008) (Figure 1.1).
The commercial crayfish harvest in Louisiana is obtained from farm production and wild capture, which is termed crawfishing. Wild harvest of crayfish has a special importance in Louisiana, and the harvest is composed by two main crayfish species: the red swamp crayfish (*Procambarus clarkii*) and the southern white river crayfish (*Procambarus zonangulus*).
The life cycles of both species are adapted to low water and high water conditions, and this cyclical period defines the annual harvest season (McClain and Romaire, 2007). However, most of the total annual harvest is composed of the red swamp crayfish, and only a small percentage of the harvest is composed of the southern white river crayfish. Recent studies have found that the southern white river crayfish (*Procambarus zonangulus*) was absent in certain areas in the Atchafalaya River Basin (Bonvillain 2012), potentially explaining to the limited contribution to the harvest.

*Procambarus clarkii* is endemic from northeastern Mexico and the southern United States, and it has been introduced (accidentally and intentionally) in all continents except Oceania and Antarctica. Thus, *P. clarkii* is considered today as the most cosmopolitan crayfish around the world, and, where invasive, the species produces the most negative impacts worldwide among introduced crayfish (Scalili et al. 2010, Treguier et al. 2011; Gonçalves et al. 2015). However, for the state of Louisiana, the commercial importance of *P. clarkii* represents an industry of more than $150 million annually (McClain 2007).

The crayfish industry production data from 2004 revealed that 2,376 people were involved in this activity. The total production of commercial crayfish was divided between producers (54%) and harvesters (46%), and their yields represent 90% and 10%, respectively, of the total 82 million pounds of crayfish produced in 2004 (Walls 2009). This trend was stable for many years, however, recent data showed that the economic value (USD) of wild harvested crayfish has decreased from 10% to 3% of the total annual harvest value from 2013 to 2015 (LSU AgCenter Summary 2014, 2015, 2016). The importance of wild harvest is related with socio-cultural factors, making that wild harvested crayfish highly desired by some consumers. Although many studies have been done to assess the crayfish fishery in terms of landings and
value (e.g. Alford and Walker 2013), the practices of wild harvesters are not well documented, and today, it is unclear how wild harvesters define fishing strategies and what are the factors that influence their decisions for starting harvesting and setting traps during the crayfish season.

**Study Area**

The Atchafalaya River Basin (ARB) located in the south-central Louisiana contains one of the largest floodplain bottomland hardwood forests in the United States (Lambou 1990) (Figure 1.2). The main source of water of the ARB is the Atchafalaya River which extends 200 km, is the most important distributary of the Mississippi River, and is one of the top five rivers in the United States based on its annual average discharge (6371 m$^3$s$^{-1}$) (Kammerer 1990).

![Figure 1.2](image)

**Figure 1.2.** The Atchafalaya River Basin located in the south-central Louisiana.
Since 1963, The Atchafalaya River receives 30% of the combined flow of the Mississippi River and the Red River through the Old River Control Structure (ORCS) (Ford and Nyman 2011). The discharge of the Atchafalaya River produces a hydrograph with a seasonal and annual variation that typically begins to increase during the fall or early winter, and reaches its peak between April and early June. The discharge decreases during late summers and early fall (Lambou 1990; Fontenot et al. 2001).

The Atchafalaya River was created due to the lateral migration of the Mississippi River during the mid-1500s, when the Mississippi River formed a bend intercepting the Red River (Fisk 1952; Piazza 2014). At this interception, the Atchafalaya River was formed, although much smaller than today; however, anthropogenic interventions continued the diversion process of the Atchafalaya River and increased its size (Russell 1940; Fisk 1944, 1952). The most important human intervention occurred after the Great Mississippi Flood of 1927 that promoted the Mississippi River and Tributaries Act of 1928 and the Jadwin Plan (Reuss 2004). The Jadwin Plan had many components, and its main objectives were isolate floodplains from the river channel and use large floodways to divert the excess floodwater. However, during 1950s, due to the hydrologic advantages (distance and altitude), a potential avulsion of the Mississippi River into the Atchafalaya River nearly occurred (Fisk 1952, Piazza 2014), and to avoid an avulsion, the U.S Army Corps of Engineers (USACE) proposed the construction of the Old River Control Structure (ORCS). This structure encompasses different features including a low sill structure, hydroelectric facility, auxiliary structure, lock and dam facility, and overbank control structure to control the diversion and the potential avulsion (Aslan et al. 2005; Benneth et al. 2013). Additionally, as part of the flood control plans, other structures were designed to operate during extreme events, such as the West Atchafalaya Floodway and the Morganza Floodway, which
was opened during the 2011 flood in the Lower Mississippi (the second highest recorded river flow diverted into the ARB; Scott et al. 2014).

Historically, the ARB covered an area of 8,345 km²; but due to natural processes and human influences, at present, it covers an area of 5,670 km², approximately divided in 3,581 km² of forested wetlands and 2,092 km² composed of marshlands and open water areas (Demas 2001; Hupp et al. 2008). As a large river system, the ARB supports a high level of biodiversity providing diverse habitats for plants and animals, and numerous ecosystem services (Calhoun 1999; Piazza 2014). These habitats consist of floodplain areas connected hydrologically during the seasonal floods periods (Alford and Walker 2013) and hydrologically disconnected with very different water quality and habitat in low water periods (Sabo et al. 1999; Kaller et al. 2011; Pasco et al. 2016). Based on elevation and dominant cover type, three major habitats regions are found in the ARB (Piazza 2014). The northern region contains a diverse bottomland hardwood forest, whereas cypress-tupelo swamps composed the middle region, and the lower region is the delta plain defined by delta wetlands habitats (Piazza 2014).

The study was focused on the Buffalo Cove Management Unit area (BCMU), located in the southwest portion of the ARB (Figure 1.3). BCMU is bordered on the north by Little Gonsoulin Bayou, Alligator Bayou and Bayou Chene, on the south by Lake Fausse Pointe Cut, on the east by the Basin main channel, and on the west by the West Atchafalaya Basin Protection Levee. BCMU was defined by the USACE as a hydrologically distinct area in 1982 for the purpose of water management to potentially restore unique historical overflow conditions (USACE 1982; USACE 2000). Presently, BCMU is affected by excess sedimentation processes, invasive species, and water quality issues (e.g., Kaller et al. 2011, 2015; Pasco et al. 2016), which threaten the fisheries habitats and ecosystem processes in the area. In order to address
solutions, the Buffalo Cove Management Unit Project has been improving water circulation and sediment management, through the improvement of interior water circulation, the introduction of river water from the upper area, the removal of barriers to north-south flow, and the prevention of sediment deposition into the interior swamp.

Figure 1.3. Buffalo Cove Management Unit at the southwest portion of the Atchafalaya River Basin.


CHAPTER 2
QUANTITATIVE AND QUALITATIVE ASSESSMENT OF CRAYFISH HARVESTING PRACTICES IN THE SOUTHERN ATCHAFALAYA RIVER BASIN AND HYDROLOGIC CONNECTIVITY INFLUENCE ON HARVESTING STRATEGIES

Introduction

Crayfishing (locally crawfishing) was adapted by European colonists and later American settlers in Louisiana from Native American fishing activities. Modern traditions of eating crayfish in Louisiana began after the arrival of Acadians around 1750-1780, and has evolved into an economically and culturally important activity in the state, known as the “crawfish state” by law (Walls 2009).

Despite early beginnings of crayfish consumption, commercial crayfish harvest did not begin until 1880. Crayfish were more popular in New Orleans than in more northern cities in the early 1900s (Walls 2009), and the perception of crayfish as a viable food increased after the great flood in 1927. During the 1930s, Percy Viosca Jr. researched important aspects of crayfish taxonomy and harvest techniques to promote the crayfish farming as a source of food and as an industrial crop (Pitre 1993). During this time, the idea of cultivating crayfish in ponds and rice fields was introduced (Walls 2009), which eventually expanded to crayfish/rice/soybean production (Huner 1994). Currently, crayfish can be obtained from farm harvest and wild harvest, with pond production contributing 88% of the harvest in 2008 (Isaacs and Lavergne 2010). Of the total wild harvest in Louisiana, the Atchafalaya River Basin (ARB) provides over 90% of the total yield (Isaacs and Lavergne 2010), although harvests from the ARB have declined over the last two decades (McClain et al. 2007).

As a large floodplain river system, the ARB is influenced by the annual flood pulse that impacts floodplain physicochemistry and the dynamics of resident biota (Sabo et al. 1999; Fontenot et al. 2001; Kaller et al. 2011; Bennett and Kozak 2016). The annual flood pulse is the
primary determinant of the magnitude of the wild crayfish harvest in the ARB, which typically starts in November, peaks between March and June, and ends in July (McClain et al. 2007; Alford and Walker 2013). Generally, the annual flood pulse defines the start and duration of the harvesting season (Bonvillain et al. 2013), hence, unlike farmed crayfish, the availability of wild harvested crayfish and their price fluctuates annually.

Seasonal hydrologic pulses have a key role in floodplain ecosystems because they control hydrologic connectivity among habitats that results in an increase or decrease of physical space, resources, and habitat for a variety of organisms (Junk et al. 1989; Thomaz et al. 2007). Hydrologic connectivity has been demonstrated to be essential to the viability of populations of many species, and the ecological integrity of the environment (Bunn and Arthington 2002; Pringle 2003). However, hydrologic connectivity can be altered by moderate human disturbances, which can contribute to losses of aquatic diversity (Pringle 2003; Fernandes et al. 2009). Considering that fisheries production in many freshwater systems is closely associated with floodplains and floodplain connectivity, hydrological alterations could affect the future of fisheries around the world (Junk et al.1989; Dudgeon 2000; Pringle et al. 2000a).

Louisiana has the largest crayfish industry in the United States (McClain et al. 2007), having changed over the last four decades from a curiosity and occasional meal to a major crop valued at $196.8 million USD in 2015 (Walls 2009; LSU AGCenter Summary 2015, 2016). Although wild-harvested crayfish has decreased from 10% to 3% of the total annual harvest value from 2013 to 2015 (LSU AGCenter Summary 2014, 2015, 2016), wild crayfish are highly desired by some consumers because of larger sizes and a strong socioeconomic and cultural importance. Additionally, the crayfish industry is a symbol of Louisiana culture, with the Breaux...
Bridge Crayfish Festival and Mudbug Madness being among the most important festivals in Louisiana (Walls 2009).

The Louisiana’s crayfish harvest is mostly composed of red swamp crayfish (*Procambarus clarkii*) and southern white river crayfish (*Procambarus zonangulus*) (McClain et al. 2007). Wild-caught *P. clarkii* production and harvest access on the floodplain are strongly dependent on hydrologic connectivity with the Atchafalaya River (McClain et al. 2007; Alford and Walker 2013). As a cosmopolitan crayfish, *P. clarkii* is well adapted to life in areas with substantial seasonal fluctuations in flow, temperature, and dissolved oxygen levels (Huner 1977; Hobbs 1972; Huner and Barr 1984; Treguier et al. 2011), although chronic exposure to adverse water quality has been reported to affect *P. clarkii* survival and fishery production (Avault et al. 1975; Melancon and Avault 1977; McClain 1999; Sladkova and Kholodkevich 2011; Bonvillain 2015). However, other than correlations between harvest levels and flood magnitude (Alford and Walker 2013), little is known about hydrologic relationships, particularly floodplain connectivity, on the ecology and exploitation of freshwater invertebrates in general and crayfish in particular (Pringle 2003; Bonvillain et al. 2012).

The ARB has experienced anthropogenic modifications to hydrologic connectivity through the construction of levees, spoil banks, and channels directing water against the natural northwest to southeast flow, which have diminished water quality and adversely impacted resident biota (Sabo et al. 1999; Fontenot et al. 2001; Rutherford et al. 2001; Podey et al. 2006; Piazza 2014; Kroes and Kraemer 2013; Kaller et al. 2011, 2015; Bennett and Kozak 2016). These alterations may also have altered production of crayfish, as well as the fishing strategies and activities of crayfish harvesters on the ARB floodplain. The purpose of this study was to assess environmental influences on crayfish harvesting practices in the ARB. I focused my
sampling efforts in the Buffalo Cove Management Unit (BCMU), which was selected due to the magnitude of historic harvesting activity by local commercial fishers. Specifically, my objectives were to: 1) determine if trap locations are randomly selected by crayfish harvesters; 2) assess whether trap locations are associated with water quality, habitat or floodplain connectivity; and 3) determine through interviews the types of information used by commercial fishers to select fishing times and locations. Data collected to investigate these relationships included water quality observations, stable isotope signatures, and trap locations along the most important access routes, as well as interviews with commercial harvesters.

Study area

Within an area of 5,670 km², the ARB is the largest floodplain bottomland hardwood forest in the United States (Lambou 1990), with floodplain areas connected hydrologically during the annual flood pulse (Alford and Walker 2013), and disconnected and heterogeneous in habitat and water quality during low water (Sabo et al. 1999; Kaller et al. 2011, 2015; Pasco et al. 2016). The Atchafalaya River receives 30% of the combined discharge of the Mississippi and Red rivers, with a flood pulse that varies substantially both seasonally and annually, typically beginning during fall or early winter, and declining through the next spring and summer (Figure 2.1; Lambou 1990; Fontenot et al. 2001). The Atchafalaya River flood pulse can be controlled through several structures on the Mississippi River operated by the U.S. Army Corps of Engineers (USACE; Ford and Nyman 2011). Water management activities on the ARB floodplain are provided by the USACE and the Louisiana Department of Natural Resources, with the Louisiana Department of Wildlife and Fisheries (LDWF) managing ARB fisheries.

The ARB is divided into 13 administrative water management units (WMUs), and the BCMU (~ 23,000 ha) is dominated by interconnected natural channels, lakes, and excavated
canals. BCMU has several connection points to the Atchafalaya river that can supply significant inputs of water to the floodplain during the flood pulse (Jones et al. 2014; Kaller et al. 2011, 2015). Although several water management projects associated with the Buffalo Cove Management Unit Project (USACE 1982, 2000) have significantly altered hydrology within the Unit, crayfish harvesting has continued to be important to local commercial fishers. The BCMU is a dynamic system, and has been subject to high levels of sedimentation, invasive fishes and aquatic plants, water quality issues, and water management activities (Kaller et al. 2011, 2015; Pasco et al. 2016).

Methods

Sample locations

Three different zones in the BCMU were selected for field studies (Figure 2.2), which included habitats dominated by cypress-tupelo swamps that typically yielded most of the crayfish harvest. Access route sampling transects were used to obtain crayfish population data, water quality data, water samples, and habitat measurements. Transects were designated based on accessibility and presence of crayfish traps, indicating active commercial fishing in these areas. I sampled 22 sites in 2015 along four transects in main access routes in the BCMU, and 19 sites along three transects in 2016 (in 2016 access to the northern transect was closed by the USACE).

Field data collection

Sampling seasons for crayfish are necessarily variable, as harvesting depends on the timing, magnitude, and duration of the annual flood pulse. Sampling seasons occurred from 6 April through 24 June in 2015, and 6 April through 30 June in 2016. During the 2015 crayfish season, I deployed 35 crayfish traps on three occasions along the sampling transects to estimate crayfish abundance (A1, B1, and C1 = 10 traps; and A2 = 5 traps; Figure 2.3). I fished
Figure 2.1. Mean of annual and seasonal variation in Atchafalaya River stage at Butte La Rose, Louisiana. The dashed line is the 10-year mean stage of the Atchafalaya River. Source: USGS (National Weather Information System); Atchafalaya River Stage at Butte La Rose, LA (USACE recording gage 03120).
Figure 2.2. Sampling locations at Buffalo Cove Management Unit (season 2015-2016).

commercial 122-cm long pillow traps constructed of 19-mm hexagonal mesh vinyl-coated wire, with a mixture of fish (Gulf Menhaden *Brevoortia patronus*) and manufactured pellets (Southern Pride Crawfish Bait, Purina Animal Nutrition, LLC.) used as bait. Traps were located next to trees and bushes and at least 20-m from each other and were checked every 24 hours, weather permitting. All captured crayfish were identified to species, counted, and sexed. To obtain information on trap locations used by commercial crayfishers, I used a laser rangefinder Bushnell Sport 850 to count traps within a 25-m band along each transect. Trap locations were recorded with a Garmin GPSmap 60CSx, and data was processed with GIS software (ArcGIS vers. 10.3, ESRI, Inc., Redlands, CA), and Program R (spdep package, Program R, R Core Team 2015).
Figure 2.3. Intensive crayfish sampling locations in Buffalo Cove Management Unit.

For these counts, I moved at 2.0-m/sec along each transect and counted both flagged traps and unflagged traps, with data expressed as the number of traps per kilometer (trap density, TD; Figure 2.4). Traps along transects A1, B and C were counted 14 times, and traps along A2 were counted 4 times between 2015 and 2016. I assumed all traps had a constant probability of detection along each transect (Thurow et al. 2012).

Water quality sites (WQ) were located at approximate 1-km intervals along the sampling transects. All WQ sites along transects A1, A2, B, and C were sampled 4 times during 2015, with
Figure 2.4. Diagram of sampling protocol along transect A trap counts.
sites along transects A1, B, and C sampled 10 times in 2016. At each site, I measured temperature (°C), pH, turbidity (NTU), dissolved oxygen (DO; mg/L), and specific conductance (mS/cm) with a YSI® 6820v2 in situ water quality sonde. When water depths were less than 1-m, I took measurements at the surface (0.25-m) and bottom of the water column, with readings taken at the surface, mid-depth, and bottom in depths greater than 1-m. Atchafalaya River stage at the Butte La Rose gage was recorded on all sampling dates as an indication of water movement into and out of the study area.

I conducted personal interviews with 23 commercial harvesters to assess fishing practices, with 20 of the surveys completed by harvesters at Bayou Benoit and Sandy Cove boat launches, and three others delivered to harvesters who used other access points. The survey consisted in a questionnaire of eleven questions without restrictions for answers (Appendix A). Harvesters provided information about their harvesting techniques, sources of information used for fishing purposes, years of experience, and demography. Information obtained was used to identify whether fishing locations chosen by harvesters were related to water quality and habitat characteristics that I measured in the BCMU.

During 2016, I measured water velocity at water quality sampling sites with a Doppler velocity meter (Sontek Flowtracker, Xylem, Inc., San Diego, CA), and collected water samples for determination of conservative isotopic tracer composition (20-ml glass vials with zero headspace, samples collected at 0.4-m depth) as an indicator of river connectivity. I added sampling sites at the Lake Fausse Pointe Cut Channel (LFPCC) for transect B and C (Figure 2.5), as these areas appeared to be additional sources of river water. A DLT-100 liquid water isotope analyzer (Los Gatos Research, San Jose, CA) was used to measure concentrations of deuterium ($^2$H or D) and oxygen18 ($^{18}$O) in water samples. These values were reported as the deviation ($\delta$)
of the ratio (R) ($^2$H/$^1$H and $^{18}$O/$^{16}$O) from that of the reference standard. Results are multiplied by a thousand and expressed in parts per mil (%): \( \delta D \) or \( \delta^{18}O = \left[ \frac{R_{\text{sample}}}{R_{\text{reference}}} - 1 \right] \times 1000 \); where \( R \) is the $^2$H/$^1$H or $^{18}$O/$^{16}$O ratio. I also calculated the deuterium excess (d) for each sample, which represents the deviation from the global meteoric water line (GMWL), expressed as:

\[ d = \delta^2H - (8 \times \delta^{18}O) \]

Figure 2.5. Sampling locations and average monthly hydrograph (Butte La Rose) at the southwest portion of the Buffalo Cove Management Unit.
Data analyses

The data set included measures of water quality, D, $^{18}$O and d concentrations, habitat, crayfish harvest, harvester surveys, and TD recorded during the crayfish harvesting seasons of 2015 and 2016. I used generalized linear models (GLMs; PROC GLIMMIX, SAS Version 9.4, SAS Institute, Inc., Cary, NC) for all comparisons, with Akaike’s Information Criterion (AIC) and $\hat{c}$ used to evaluate the best model based on combinations of link functions and probability distributions, and whether the models should include random effects. AIC achieves asymptotic efficiency, which is a minimized prediction error that maximizes the predictive accuracy, and $\hat{c}$ is the value of Pearson chi-square divided by the degrees of freedom for the model, which attributes fit to the relationship between the variance of model predicted values and observed values ($\hat{c}$= Pearson x$^2$/ df; Shibata 1976; Aho et al. 2014).

I used GLMs to test exploratory models and define the best fitting model of TD by comparing surface, middle, bottom and average water column values of WQ measurements in separate GLMs. The best fitting model consisted of mid-WQ measures, a cumulative logit link and a multinomial distribution. Based on the results of this exploratory model, I used mid-WQ data for subsequent analyses. I also used a GLM and Tukey-Kramer post-hoc analysis ($\alpha$ =0.05) to assess differences in water quality, habitat and TD between years and among northern, middle, and southern regions of the BCMU.

Prior to constructing statistical models to relate TD with WQ, survey answers, and isotopic composition of water, I used my trapping data to confirm the presence of crayfish at the study sites, and whether trap distributions exhibited spatial autocorrelation. Spatial distribution patterns were analyzed with the Pearson Chi-square Quadrat Test and Nearest Neighbor Test of Complete Spatial Randomness (spdep package, Program R, R Core Team 2015). These tests
used geographic coordinates to analyze trap distributions along transects and determine if the traps followed a random or clustered distribution.

Descriptive statistics were used to analyze harvester answers to survey questions with special focus on information about decision factors that helped define the start of the harvesting season and the location of commercial traps. I also summarized information on harvester access to the internet, i.e., whether it was used as a source of information, and how useful internet information was in terms of their fishing strategies.

Following tests of spatial autocorrelation and survey answers, I used three GLMs to evaluate whether water quality measurements, variables identified during fisher interviews, and isotopic composition explained TD among regions. All GLMs used a log link and a negative binomial distribution. The first GLM incorporated region, temperature, pH, specific conductance, DO, depth, turbidity and interactions among regions as explanatory variables. The second GLM incorporated region, mid-column depth, mid-column turbidity, river stage, and the interaction between depth x turbidity, and depth x turbidity$^2$ as explanatory variables (interactions were included in the model to identify potential linear and quadratic patterns in the data). For the third GLM, adjusted d values were calculated as the value of d at a sampling site minus the value of d from LFPCC for the same date, expressed as $\Delta d$. Explanatory variables in the model included region, $\Delta d$, $\Delta d^2$, and $\Delta d^3$ to identify quadratic and cubic patterns in the data.

**Results**

**Water quality and habitat parameters**

Overall WQ data was well within the tolerable ranges for crayfish (Table 2.1), although significant differences among zones in all parameters except specific conductance were evident (Table 2.2). Overall, field measurements indicated Region C had higher mean values of
temperature and depth, but lower mean values of pH, DO and turbidity than region A and B (Table 2.2). In addition, sample sites in 2016 had lower mean values of temperature, pH, specific conductance, and turbidity relative to 2015 (Table 2.3). Differences in water quality were not reflected in TD in the three zones (Table 2.2), although TD was significantly higher in 2015 relative to 2016 (Table 2.3).

Table 2.1. Water quality variables from mid-column measurements of sampling seasons 2015 and 2016.

<table>
<thead>
<tr>
<th>WQ variables</th>
<th>N</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>232</td>
<td>24.32</td>
<td>2.75</td>
<td>15.49</td>
<td>29.47</td>
</tr>
<tr>
<td>pH</td>
<td>232</td>
<td>6.99</td>
<td>0.27</td>
<td>6.32</td>
<td>8.18</td>
</tr>
<tr>
<td>Specific conductance (mS/cm)</td>
<td>232</td>
<td>0.31</td>
<td>0.08</td>
<td>0.19</td>
<td>0.56</td>
</tr>
<tr>
<td>Dissolved oxygen (mg/L)</td>
<td>232</td>
<td>3.41</td>
<td>2.14</td>
<td>0.18</td>
<td>7.53</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>232</td>
<td>1.03</td>
<td>0.39</td>
<td>0.42</td>
<td>2.13</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>232</td>
<td>46.99</td>
<td>41.35</td>
<td>0.20</td>
<td>207.80</td>
</tr>
</tbody>
</table>

Fishery-independent crayfish sampling

I trapped 350 crayfishes in 2015, with 97% of the catch comprised of *P. clarkii* (40% males, 60% females), and 3% *P. zonangulus* (33% males, 67% females). *P. clarkii* was collected from all zones, whereas *P. zonangulus* was collected only from transects A1 and C.

Spatial distribution of crayfish traps

Results of Chi-Squared Quadrat and Nearest Neighbor Tests showed evidence of significant spatial autocorrelation (clustering) of commercially-fished traps at the study sites. It was clear that crayfish harvesters were setting traps in specific areas inside the BCMU (p-value < 0.05 for all days; Table 2.4; Figure 2.6).
Table 2.2. Means and standard deviations of TD and WQ variables by regions sampled during crayfish seasons of 2015-2016. Significant differences among zones as determined by pairwise estimates of means differences through Tukey-Kramer post-hoc analysis. Means with different letter are significantly different from each other (α = 0.05).

<table>
<thead>
<tr>
<th>Region</th>
<th>TD</th>
<th>Temp °C</th>
<th>pH</th>
<th>SpConduc mS/cm</th>
<th>DO mg/lt</th>
<th>Depth m</th>
<th>Turbid NTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>22.30 (21.43)</td>
<td>23.94 (2.47)</td>
<td>A 7.07 (0.31)</td>
<td>A 0.32 (0.08)</td>
<td>A 4.43 (2.06)</td>
<td>A 0.71 (0.15)</td>
<td>A 65.44 (47.72)</td>
</tr>
<tr>
<td>B</td>
<td>25.96 (25.14)</td>
<td>23.40 (3.25)</td>
<td>AB 7.03 (0.24)</td>
<td>AB 0.3 (0.08)</td>
<td>A 3.91 (2.08)</td>
<td>AB 0.93 (0.37)</td>
<td>B 50.62 (30.51)</td>
</tr>
<tr>
<td>C</td>
<td>22.18 (25.89)</td>
<td>24.97 (2.46)</td>
<td>C 6.92 (0.24)</td>
<td>C 0.31 (0.09)</td>
<td>A 2.62 (1.90)</td>
<td>C 1.24 (0.35)</td>
<td>C 35.57 (37.64)</td>
</tr>
</tbody>
</table>

Table 2.3. Means and standard deviations of TD and WQ parameters by year (2015-2016). Significant differences between years as determined by pairwise estimates of means differences through Tukey-Kramer post-hoc analysis. Means with different letter are significantly different from each other (α = 0.05).

<table>
<thead>
<tr>
<th>Year</th>
<th>TD</th>
<th>Temp °C</th>
<th>pH</th>
<th>SpConduc mS/cm</th>
<th>DO mg/lt</th>
<th>Depth m</th>
<th>Turbid NTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>30.76 (27.74)</td>
<td>25 (2.89)</td>
<td>A 7.14 (0.28)</td>
<td>A 0.34 (0.12)</td>
<td>A 3.14 (1.85)</td>
<td>A 0.99 (0.38)</td>
<td>A 55.74 (52.66)</td>
</tr>
<tr>
<td>2016</td>
<td>19.42 (21.95)</td>
<td>23.95 (2.61)</td>
<td>B 6.9 (0.22)</td>
<td>B 0.29 (0.05)</td>
<td>B 3.55 (2.26)</td>
<td>A 1.04 (0.39)</td>
<td>A 42.30 (33.02)</td>
</tr>
</tbody>
</table>
Table 2.4. Tests of spatial autocorrelation of crayfish traps during the 2016 crayfishing season (d.f. = 17 for all tests).

<table>
<thead>
<tr>
<th>Date</th>
<th>$\chi^2$ Test Statistic</th>
<th>P-value</th>
<th>Date</th>
<th>$\chi^2$ Test Statistic</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 6th</td>
<td>245.89</td>
<td>&lt;0.01</td>
<td>May 26th</td>
<td>392.06</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>April 8th</td>
<td>254.89</td>
<td>&lt;0.01</td>
<td>June 2nd</td>
<td>495.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>May 3rd</td>
<td>219.66</td>
<td>&lt;0.01</td>
<td>June 8th</td>
<td>362.58</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>May 4th</td>
<td>237.9</td>
<td>&lt;0.01</td>
<td>June 16th</td>
<td>578.41</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>May 10th</td>
<td>180.95</td>
<td>&lt;0.01</td>
<td>June 23rd</td>
<td>567.95</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>May 12th</td>
<td>392.12</td>
<td>&lt;0.01</td>
<td>June 30th</td>
<td>379.63</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>May 18th</td>
<td>362.58</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2.6. Spatial clustering of crayfish traps on 26 May 2016.
Interview results

Of 24 fishers that I contacted, 23 (96% response rate) answered survey questions, which represented almost 10% of the potential licensed commercial crayfish harvesters in the southwestern ARB (public license sales data, LDWF). Data indicated 52% of harvesters had between 20 and 40 years of experience (Figure 2.7). Only 48% were aware that potentially useful crayfishing information was available on the internet, although 90% of these respondents considered internet sources to be beneficial to their fishing practices, particularly information on river stage, temperature, weather, water flow, tides, and flooding.

Figure 2.7. Experience of crayfish harvesters in the Buffalo Cove Management Unit.

Overall, 88% of harvesters considered water depth to be the most important factor regarding initiation and continuation of crayfishing. Almost 50% of harvesters considered tradition to be an important aspect of season initiation, and 40% considered water color (a
surrogate for turbidity) to be important when determining trapping locations. In contrast, scientific information was not relevant to harvester fishing activities (Figure 2.8).

**Figure 2.8.** Influential factors on the crayfish harvesting season initiation and selection of fishing locations based on information collected through harvester surveys.

**Model#1: TD explained by WQ parameters**

Analyses indicated that temperature \( t_{170} = -3.83, P = 0.0002 \) and turbidity \( t_{170} = -4.45, P < 0.0001 \) significantly influenced TD. For temperature, TD decreased at the rate of 0.48 \( (\pm 0.12 \text{ SE}) \) traps per °C and did not vary among regions. For turbidity, TD decreased 0.07 \( (\pm 0.02 \text{ SE}) \) traps per increasing NTU, with a significantly greater effect (fewer traps) in
Region A relative to Regions B ($t_{170} = 2.20, P = 0.03$) and C ($t_{170} = 4.81, P < 0.0001$). Levels of DO, depth, pH, and specific conductance did not influence TD in the Unit (Table 2.5).

### Table 2.5. Model of TD explained by WQ parameters, and effects of interactions among regions.

Degrees of freedom were 170 for all variables. Underlined $=$ statistical significance ($\alpha = 0.05$).

| Effect               | Estimate | Standard Error | t Value | Pr > |t| | Region comparison |
|----------------------|----------|----------------|---------|-------|---------------|-------------------|
| Intercept            | 8.32     | 5.79           | 1.44    | 0.15  |               |                   |
| Region               | -7.84    | 8.04           | -0.98   | 0.33  | A-C           |                   |
| Region               | 2.36     | 10.87          | 0.22    | 0.83  | B-C           |                   |
| Region               | -10.20   | 10.75          | -0.95   | 0.34  | A-B           |                   |
| Temperature °C       | -0.48    | 0.12           | -3.83   | 0.0002|               |                   |
| pH                   | 1.08     | 0.91           | 1.19    | 0.23  |               |                   |
| Specific Conductance mS/cm | 3.74    | 2.53           | 1.48    | 0.14  |               |                   |
| DO mg/L              | -0.28    | 0.21           | -1.34   | 0.18  |               |                   |
| Depth m              | -0.04    | 0.59           | -0.07   | 0.95  |               |                   |
| Turbidity NTU        | -0.07    | 0.02           | -4.45   | <.0001|               |                   |
| Temperature*region   | 0.18     | 0.26           | 0.72    | 0.47  | A-C           |                   |
| Temperature*region   | 0.12     | 0.21           | 0.56    | 0.58  | B-C           |                   |
| Temperature*region   | 0.07     | 0.28           | 0.23    | 0.82  | A-B           |                   |
| pH*region            | 0.34     | 1.39           | 0.24    | 0.81  | A-C           |                   |
| pH*region            | -0.61    | 1.80           | -0.34   | 0.73  | B-C           |                   |
| pH*region            | 0.95     | 1.88           | 0.50    | 0.61  | A-B           |                   |
| Specific Cond.*region | -0.17  | 5.13           | -0.03   | 0.97  | A-C           |                   |
| Specific Cond.*region | -0.56  | 4.30           | -0.13   | 0.90  | B-C           |                   |
| Specific Cond.*region | 0.39   | 5.66           | 0.07    | 0.94  | A-B           |                   |
| DO*region            | -0.27    | 0.30           | -0.90   | 0.37  | A-C           |                   |
| DO*region            | 0.01     | 0.33           | 0.02    | 0.98  | B-C           |                   |
| DO*region            | -0.28    | 0.34           | -0.84   | 0.40  | A-B           |                   |
| Depth*region         | 0.36     | 2.50           | 0.14    | 0.89  | A-C           |                   |
| Depth*region         | -1.92    | 2.59           | -0.74   | 0.46  | B-C           |                   |
| Depth*region         | 2.28     | 3.50           | 0.65    | 0.52  | A-B           |                   |
| Turbidity*region     | 0.08     | 0.02           | 4.81    | <.0001| A-C           |                   |
| Turbidity*region     | 0.04     | 0.02           | 1.66    | 0.10  | B-C           |                   |
| Turbidity*region     | 0.04     | 0.02           | 2.20    | 0.03  | A-B           |                   |
Model#2: TD explained by harvester-selected variables and WQ field observations

The second model indicated harvesters considered water depth as the most relevant factor regarding season initiation and trap location. The model for depth ($t_{183} = 2.29, P = 0.02$) agreed with harvester responses, suggesting that TD increased at the rate of 1.77 ($\pm 0.77$ SE) traps for each meter of depth in the water column. Results also suggested a relationship between depth and turbidity ($t_{183} = -4.80, P < 0.0001$), and depth and turbidity$^2$ ($t_{183} = 2.76, P = 0.01$), highlighting the influence of river water input on water color. Analyses also indicated that TD increased at the rate of 0.16 ($\pm 0.07$ SE) traps for each foot of depth increase in Atchafalaya River stage ($t_{183} = 2.17, P = 0.03$; Table 2.6). Model results suggested most traps were set in less turbid water (NTU < 69.4) in depths of 1-3 m, with fewer traps set in deeper (depth > 3.6 m) and highly turbid water (NTU > 100; Figure 2.9).

**Table 2.6.** Model of TD explained by variables selected by harvesters and WQ field observations. Degrees of freedom were 183 for all variables. Underlined = statistical significance ($\alpha = 0.05$).

| Effect             | Region | Estimate | SE  | t Value | Pr > |t| |
|--------------------|--------|----------|-----|---------|------|---|
| Intercept          |        | 0.19     | 0.79| 0.24    | 0.81 |
| Region             | A      | 0.34     | 0.50| 0.66    | 0.51 |
| Region             | B      | 0.23     | 0.39| 0.59    | 0.56 |
| Region             | C      | 0.00     | 0.00|        |      |
| Depth (m)          |        | 1.77     | 0.77| 2.29    | 0.02 |
| Turbidity (NTU)    |        | 0.03     | 0.01| 1.94    | 0.05 |
| Depth*Turbidity    |        | -0.07    | 0.02| -4.80   | <.0001|
| Depth*Turbidity$^2$|        | 0.00015 | 5.5E-05| 2.76   | 0.01 |
| River stage        |        | 0.16     | 0.07| 2.17    | 0.03 |
**Figure 2.9.** Plot of TD means and values of mid-turbidity and mid-depth in Buffalo Cove Management Unit during sampling season 2015-2016.

Model#3. TD explained by isotopic composition of water (Δd ‰) by region

The model relating TD to Δd (‰) had a significant Δd^2 relationship (t_{58} = -2.10, P = 0.04) and Δd^3 relationship (t_{58} = -2.10, P = 0.04) for transect A. TD initially showed a non-significant decreasing trend when Δd was less than -3, and then increased at the rate of 2.97 (± 0.28 SE) traps per unit of Δd when Δd was between -2 and 0. When Δd was greater than 0, TD decreased at a rate of 4.24 (± 0.61 SE) traps per unit of Δd (Table 2.7; Figure 2.10). The values of Δd suggested areas more disconnected from the river (LFPCC) tended to have a lower TD in BCMU. Based on these analyses, it appears that TD increased at sites experiencing inflows of river water, which was primarily from the LFPCC (Figure 2.11). For transects B and C, Δd did not show any effect on TD. The predictive model for TD explained by Δd in region A is:

\[ TD = 4.51 + 0.25(\Delta d) - 4.79(\Delta d^2) - 1.27(\Delta d^3) \]
Table 2.7. Model of TD and isotopic composition of water (Δd ‰) by region. Degrees of freedom were 58 for all variables. Underlined = statistical significance (α = 0.05).

| Effect            | Region | Estimate | Standard Error | t Value | Pr > |t| |
|-------------------|--------|----------|----------------|---------|------|-----|
| Intercept         |        | 2.94     | 0.33           | 8.85    | <.0001 | |
| Region A          |        | 1.57     | 1.13           | 1.39    | 0.17  | |
| Region B          |        | 0.72     | 0.70           | 1.02    | 0.31  | |
| Region C          |        | 0.86     | 1.24           | 0.69    | 0.49  | |
| Δd (region) A     |        | 0.25     | 0.73           | 0.34    | 0.74  | |
| Δd (region) B     |        | -1.20    | 0.87           | -1.38   | 0.17  | |
| Δd (region) C     |        | 0.26     | 0.27           | 0.98    | 0.33  | |
| Δd^2 (region) A   |        | -4.79    | 2.28           | -2.10   | 0.04  | |
| Δd^2 (region) B   |        | -1.35    | 0.82           | -1.63   | 0.11  | |
| Δd^2 (region) C   |        | 0.03     | 0.09           | 0.29    | 0.77  | |
| Δd^3 (region) A   |        | -1.27    | 0.61           | -2.10   | 0.04  | |
| Δd^3 (region) B   |        | -0.26    | 0.17           | -1.53   | 0.13  | |
| Δd^3 (region) C   |        | -0.05    | 0.03           | -1.48   | 0.14  | |

Figure 2.10. TD in region A explained by changes in isotopic composition of water (Δd ‰). Δd ‰ = 0 indicates no difference of isotopic composition (potential mixing) between sampling sites and river water.
Figure 2.11. Mean of TD and variation in deuterium excess (δd ‰) at sampling sites in transect A during May and June of 2016.
Discussion

The goal of this project was to combine field observations with harvester interviews to describe crayfishing practices of harvesters in the BCMU. My results provide insights into the decision-making process of harvesters and their fishing strategies. First, temperature and turbidity had an effect on the density of traps fished in the Unit. Interestingly, the effects of turbidity on TD were different between the two models I ran; Model 1 indicated a variable effect of turbidity on TD depending on region, which was negative in region C and positive in region A. Conversely, Model 2 indicated a quadratic relationship between turbidity with depth without regard to region that indicated an initial decline in TD with increasing depth and turbidity and then a slightly increasing relationship with depth and turbidity. Turbidity levels are related to water inputs from the Atchafalaya River, which is usually turbid, but provides well oxygenated water that can positively influence crayfish physiology and growth (Hupp et al. 2008; Piazza 2014; Bonvillain et al. 2015). Results also show a negative effect of temperature on TD, which likely reflects the initiation of crayfishing during the spring flood pulse when water temperatures are lower, and the cessation of crayfishing water temperature increases as water levels stabilize on the floodplain (Pollard et al. 1983; Bonvillain et al. 2015; Pasco et al. 2016). Although harvesters are not likely measuring water temperature directly, they are probably using a combination of air temperature and experience in determining appropriate times to begin fishing.

Second, harvesters also use water depth as a trigger of fishing season initiation, which has been anecdotally observed prior to this study (e.g., McLain et al. 2007, Bonvillain et al. 2013). Harvester’s answers to survey questions showed that tradition is an important consideration about harvest initiation, which I interpret as empirical knowledge developed from trial and error fishing through time, which also has been reported in other crustacean fishing activities (e.g., Priyambodo et al. 2015). For trap placement, I hypothesized that water depth was considered
important by harvesters as well, but it was not clear from survey evidence, as only 52% of surveys that reported water depth as important. Third, water color (closely related to turbidity) also was reported as important regarding trap placement, which was supported by field observations, and suggests that deciding where to put traps is a multivariate decision with regard to temperature, turbidity, and probably flow velocity.

Finally, and potentially most importantly, by combining field observations with the harvester’s responses, I identified an interactive relationship between water depth and water color (turbidity) that strongly indicated that deeper (> 3 m) and more turbid (NTU > 69.4) areas were avoided as trapping locations. Based on harvester responses, it is likely that, although a less common response, tradition is guiding trap placement. In other words, traps are placed in environmental conditions of depth and water color associated with trial and error experiences, rather than any scientifically derived understanding of the roles of depth and turbidity on crayfish biology.

Although many results supported earlier anecdotal observations of crayfish harvesting (e.g., Pollard et al. 1983; McLain et al. 2007; Bonvillain et al. 2013), the avoidance deep and muddy water as trapping locations was surprising. Generally, in the ARB, muddy water has been associated with sediment from the Atchafalaya River (Hupp et al. 2008) and, thus, higher water quality and more nutrients (Sabo et al. 1999; Piazza 2014; Bonvillain et al. 2013; Kaller et al. 2011, 2015), which would be assumed to be beneficial for crayfish production (Bonvillain et al. 2012). However, the avoidance of deeper, more turbid areas could also be related to the costs of fishing. Deep and muddy water conditions in the ARB occur through the rising limb and peak of the flood pulse. During this period, river water inputs reduce water temperatures, which influence the type of bait required for fishing. Fish is the recommended bait in low water
temperatures (< 21 °) and is more expensive than manufactured baits (Jhonson et al. 2008).

Based on my results, harvesters may be relating muddy water to river water inputs, and adjusting fishing effort based on bait type and the operational costs of harvesting. Selecting the optimal combination of baits (fish or formulated bait) according to perceived water temperatures may improve profits (Jhonson et al. 2008).

Use of conservative tracers (δD and δ18O) is one of the best methods for delineating hydrologic flowpaths and integrating hydrologic connectivity with ecological and ecosystem studies (Genereux and Hooper 1998; Tetzlaff 2007; Kaller et al. 2015). My results indicated that TD was affected by Δd, suggesting that connectivity of the floodplain to the permanent water bodies (e.g., LFPCC) influences TD. Most of the trapping effort was observed at Δd values between -1‰ and +1‰, indicative of mixing of floodplain and river water (through the LFPCC). More negative values of Δd suggest elevated inputs to the floodplain, which might preclude trap placement because of higher depths and/or flow velocities. Positive values of Δd indicate disconnection from the river water, and may be associated with higher water temperatures and reduced DO concentrations, conditions that are characteristic on the ARB floodplain later in the flood pulse (Pasco et al. 2016). Because the market relies on live crayfish, and crayfish mortality is often high in warmer, low-DO water (confirmed by field observations), crayfish harvesters may be avoiding these regions. Because of the relationship between evaporation and d, variation of Δd likely reflects the relationships of temperature, turbidity and depth on TD that were evident in the other two TD models.

Previous studies have linked floodplain connectivity with elevated water quality, habitat diversity, and biodiversity (Sabo et al. 1999; Pringle et al. 2000b; Bright et al. 2010; Kaller et al. 2011; Bonvillain et al. 2013; Bonvillain et al. 2015; Pasco et al. 2016), although the benefits of
river connectivity can be substantially reduced with high spatial coverage of aquatic macrophytes (Kaller et al. 2015). Macrophyte-associated declines in water quality were not evident in the BCMU during my study, primarily because I sampled earlier in the year, and plant density typically increased after the crayfishing season. Overall, my results indicate an important link between crayfish fisheries production and river connectivity. Faunal productivity, based on conservative tracer studies of trophic structure and floodplain connectivity, have been the focus of other investigations (e.g. Fry 2002; Jackson et al. 2013). However, to my knowledge, no studies have combined isotopic assessment of river connectivity with fishing activities on the adjacent floodplain. If TD can be considered a surrogate for crayfish density (e.g., Hubert et al. 2012; Murie et al. 2012), associations of higher TD with increased floodplain connectivity suggests that areas of mixed river and swamp water supported high primary (e.g. Araujo-Lima et al. 1986; Hamilton et al. 1992; Thor and Delong 2002; Jackson et al. 2013) and secondary productivity.

Understanding how ecological, economic and social factors influence fishing strategies is always challenging. With few published studies on the harvest of wild crayfish, generalizing these results to other crayfish harvesters in the southeastern United States are difficult. However, other trap-based crustacean fisheries follow one of two patterns. First, some fisheries of mobile crustaceans, such as lobster (*Palinuridae sp.*) or snow crab (*Chionoecetes opilio*), use a searching process in which tradition and previous knowledge of the area (abundance and ecological influences of target species) play an important role (Murray and Ings 2015). In these systems, harvesting locations are selected through trial and error, i.e. traps are deployed in potentially successful areas, checked frequently, and moved if unsuccessful (Priyambodo et al. 2015).
Alternatively, in crustacean fisheries that target more sedentary and less mobile species, such as blue crab (*Callinectes sapidus*), traps are set in areas associated with past success, based on geographic location, season, tide, and environmental conditions, which influence the productivity of fishing areas (Guillory et al. 2001; Mistiaen et al. 2003). Based on field observations and harvester responses, most of the ARB crayfish harvesting practices are more similar to the second pattern of setting traps where conditions suggest success and keeping traps in these locations for relatively long periods of time. Some reports indicate that crayfish harvesting developed as an outgrowth from coastal crab harvesting (J. Lively, Louisiana Sea Grant, personal communication), and LDWF license data indicate that many individuals engage in both crayfish and crab fishing (J. Isaacs, LDWF, personal communication). Therefore, similarities between crayfish and crab harvesting practices makes sense, although crayfish harvesters probably move their traps searching for better yield during the crayfish season, reflecting changes in environmental conditions on the floodplain as the flood pulse progresses.

The crayfish industry (farm-raised and wild harvest) is the most valuable fishery in the state of Louisiana (Louisiana Ag Center 2016), but the stock dynamics and harvesting characteristics of the wild *P. clarkii* fishery are not well understood (Bonvillain et al. 2013). In particular, development of an effective management framework for the commercial crayfish fishery needs a better understanding of the socioeconomic and ecological factors that interact to shape harvesting strategies and crayfish production throughout the flood pulse. Maintaining productive commercial fisheries is an important goal of ARB management (Haydel and Newman 2016), and my results reinforce the importance of maintaining floodplain-river connectivity during the harvesting season to maximize the economic return from this fishery (Alford and Walker 2013). River inputs to the floodplain, especially early in the spring, have been
demonstrated to be beneficial to water quality (Sabo et al. 1999; Kaller et al. 2011; Pasco et al. 2016), to floodplain-based fishes (Fontenot et al. 2001), and presumably, to commercial crayfish stocks (Bonvillain et al. 2012). Successful commercial crayfish management, as in other crustacean fisheries, must be able to integrate organismal dynamics, habitat quality, and socioeconomic characteristics of the fishery, all supported by a theoretical framework provided by scientific research (Johnson et al. 2010). My research suggests that ARB water management projects that can promote river-floodplain connectivity will be most beneficial to the crayfishing industry and the Louisiana natural resource economy.
Literature cited


Louisiana State University Agricultural Center (LSUAC). 2015. Louisiana summary 2015: agricultural and natural resources. Louisiana State University Agricultural Center publication 2382, 1/17 revision, Baton Rouge.


APPENDIX A
CHAPTER 2 INSTITUTIONAL REVIEW BOARD PERMISSION

ACTION ON PROTOCOL APPROVAL REQUEST

TO: Michael Keller
Renewable Natural Resources

FROM: Denny Landin
Chair, Institutional Review Board

DATE: January 22, 2016

RE: IRB# 3685

TITLE: Influence of Water Quality Parameters on the Availability of Wild Crayfish Harvest Locations in Buffalo Cove Water Management Unit, Atchafalaya River Basin


Review type: Full ___ Expedited X ___ Review date: 1/22/2016

Risk Factor: Minimal X ___ Uncertain _____ Greater Than Minimal_______

Approved ___ X ___ Disapproved__________

Approval Date: 1/22/2016 Approval Expiration Date: 1/21/2017

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 50

LSU Proposal Number (if applicable):

Protocol Matches Scope of Work in Grant proposal: (if applicable) ________

By: Denny Landin, Chairman

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING – Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects.
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
8. SPECIAL NOTE: Since interviews are in person signed consent is needed. Maintaining separate files for the signed consents and interview data will protect anonymity.

*All investigators and support staff have access to copies of the Belmont Report, LSU’s Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb

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APPENDIX B
CHAPTER 2 SURVEY APPLIED TO HARVESTERS

Consent Form

1. Study Title: Influence of water quality parameters on the availability of wild crayfish harvest location in the Buffalo Cove Water Management Unit, Atchafalaya River Basin.

2. Performance Site: Sandy Cove Boat Launch, Iberia Parish, Louisiana

3. Investigators: The following investigators are available for questions about this study, M-F, 8:00 a.m. - 4:30 p.m.
   Dr. Michael Kaller, 225-578-0012
   Mr. Ivan Vargas-Lopez, 225-578-4145

4. Purpose of the Study: The main purpose of this study is to determine between field parameters and the crayfishers’ experience what are the most important factors that define the presence and spatial distribution of available wild crawfish harvest locations in Buffalo Cove Water Management Unit of the Atchafalaya River Basin.

5. Subject Inclusion: Individuals between the ages of 18 and 65 who engage in commercial wild crayfish harvest in the Atchafalaya River basin.

6. Number of subjects: 50

7. Study Procedures: For 6 months, during the crayfish harvest season, weekly access point/central location intercept interviews will be performed on crayfishers until 50 consenting participants are obtained.

8. Benefits: Data will be enhance publically available resources for crayfishers, assist in water management decisions, and provide baseline information on harvest practices.

9. Risks: No identifying information will be collected.

10. Right to Refuse: Subjects may choose not to participate or to withdraw from the study at any time without penalty or loss of any benefit to which they might otherwise be entitled.

11. Privacy: Results of the study may be published, but no names or identifying information is being collected.

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about subjects’ rights or other concerns, I can contact Dennis Landin, Institutional Review Board, (225) 578-8692, irb@lsu.edu, www.lsu.edu/irb.
Thank you for agreeing to take part in this important study. We are conducting a study for The School of Renewable Natural Resources at Louisiana State University. Your answers will help us to develop better and more accurate information about the environmental conditions related with crawfishing in the Atchafalaya River Basin. This survey should only take 10-15 minutes. Your responses are voluntary and will be strictly confidential. Responses will not be identified by individual. All responses will be compiled together and analyzed as a group.

If you have any questions or concerns, please contact:

Mike Kaller, Ph.D.
Associate Professor
Renewable Natural Resources Building
Louisiana State University
Baton Rouge, LA 70803
phone: (225) 578-0012
email: mkalle1@lsu.edu

Where are you from?
☐ From Louisiana
☐ Not from Louisiana

If not from Louisiana: ____________________________________________________________

1. How many years of experience do you have?
______________________________

2. Are you aware that information about water conditions are available on the internet?
☐ Yes ☐ No

2.1. How did you learn about it?
__________________________________________________________________________

2.2. Do you use the information for your fishing activities?
☐ Yes ☐ No

2.3. Is the information useful?
☐ Yes ☐ No

2.4. If the answer in the question 2.3 was Yes, What data do you consult?
__________________________________________________________________________
2.5. If the answer in the question 2.3 was No: Why?

________________________________________________________________________________

3. What factors make you start the crawfishing season?

☐ Tradition / Past experience
☐ Water color
☐ Water movement
☐ Water Depth
☐ Distance / access
☐ Water smell
☐ Scientific information
☐ Trees around / bushes
☐ Amount of traps in the area
☐ Others: ______________________________________________________________________

________________________________________________________________________________

4. How many traps do you set in the ARB during the crawfish season?

________________________________________________________________________________

5. What do you consider a good yield in (sac/traps)?

________________________________________________________________________________

________________________________________________________________________________

6. Where do you set most of your traps?

☐ Buffalo Cove
☐ Fausse Pointe
☐ Grand River
☐ Lake Verret
☐ Other: ______________________________________________________________________

________________________________________________________________________________
7. According to your experience to select a location to set your traps which one(s) of these aspects is/are important?

- Tradition / Past experience
- Water color
- Water movement
- Water Depth
- Distance / access
- Water smell
- Scientific information
- Trees around / bushes
- Amount of traps in the zone

8. What size of trap do you use?
________________________

9. How often do you check and bait your traps?

- Every day
- Every two days
- Every three days
- Once per week
- Other: __________________________

10. What do you use as bait?

- Fishes: ___________________________________________________________
- Pellet baits
- Others (specify) ___________________________________________________

11. Is there any relationship between the location of your traps and the amount and kind of bait?

- Yes
- No

11.1. If the answer was yes in the previous question: What kind of relationship?
______________________________________________________________
______________________________________________________________

Comments:
______________________________________________________________


APPENDIX C
CHAPTER 2 SUPPLEMENTAL FIGURES OF SPATIAL DISTRIBUTION OF TRAPS IN TRANSECTS AT BUFFALO COVE MANAGEMENT UNIT

Figure C.1. Spatial location of traps (April 6th and 8th 2016). Results suggested that harvester set traps in a cluster distribution. April 6th: $\alpha = 0.05. X^2 = 245.89; df = 17, p$-value <0.01. April 8th: $\alpha = 0.05. X^2 = 254.89; df = 17, p$-value <0.01.
Figure C.2. Spatial location of traps (May 3rd and 4th 2016). Results suggested that harvester set traps in a cluster distribution. May 3rd: $\alpha =0.05$. $X^2=219.66$; df =17, p-value < 0.01. May 4th: $\alpha =0.05$. $X^2=237.90$; df =17, p-value < 0.01.
Figure C.3. Spatial location of traps (May 10th and 12th 2016). Results suggested that harvester set traps in a cluster distribution. May 10th: $\alpha = 0.05$. $X^2 = 180.95$; df = 17, p-value < 0.01. May 12th: $\alpha = 0.05$. $X^2 = 392.12$; df = 17, p-value < 0.01.
Figure C.4. Spatial location of traps (May 18\textsuperscript{th} 2016). Results suggested that harvester set traps in a cluster distribution. May 18\textsuperscript{th}: \( \alpha =0.05 \). \( X^2=362.58 \); df =17, p-value <0.01.
Figure C.5. Spatial location of traps (May 26\textsuperscript{th} 2016). Results suggested that harvester set traps in a cluster distribution. May 26\textsuperscript{th}: $\alpha = 0.05$. $X^2 = 392.06; \text{df} = 17, p\text{-value} < 0.01.$
Figure C.6. Spatial location of traps (June 2\textsuperscript{nd} 2016). Results suggested that harvester set traps in a cluster distribution. June 2\textsuperscript{nd}: $\alpha = 0.05$. $X^2 = 495.01$; df $= 17$, p-value $< 0.01$. 
Figure C.7. Spatial location of traps (June 8th 2016). Results suggested that harvester set traps in a cluster distribution. June 8th: $\alpha =0.05$. $X^2=362.58$; df =17, p-value <0.01.
Figure C.8. Spatial location of traps (June 16th 2016). Results suggested that harvester set traps in a cluster distribution. June 16th: $\alpha = 0.05$. $X^2=578.41$; df $=17$, p-value $<0.01$. 
Figure C.9. Spatial location of traps (June 23\textsuperscript{th} 2016). Results suggested that harvester set traps in a cluster distribution. June 23\textsuperscript{th}: \(\alpha =0.05\). \(X^2 = 567.95\); df =17, p-value <0.01.
Figure C.10. Spatial location of traps (June 30th 2016). Results suggested that harvester set traps in a cluster distribution. June 30th: $\alpha = 0.05$. $X^2 = 379.63$; df = 17, p-value < 0.01.
APPENDIX D
CHAPTER 2 SUPPLEMENTAL FIGURES OF LAND SURFACE TEMPERATURE (LANDSAT 8 SATELLITE IMAGES)

Figure D.1. Land surface temperature analysis (April 5th of 2016).
Figure D.2. Land surface temperature analysis (May 7th of 2016).
Figure D.3. Land surface temperature analysis (June 8th of 2016).
VITA

Ivan Alexis Vargas Lopez, is a native of Chiriqui, Panama. He attended Zamorano University in Tegucigalpa, Honduras from Spring 2008 to Fall 2011 where he earned his Bachelor of Science Degree in Socioeconomic Development and Environmental Sciences (Cum Laude). During Spring 2011 he participated in an internship at the Hardwood Tree Improvement and Regeneration Center at Purdue University, where he worked as a field technician. Before becoming a graduate student in the School of Renewable Natural Resources at Louisiana State University in the Spring of 2015, he worked as manager of the regional nursery for Panamanian Department of Agricultural Development in Chiriqui. At this position, he had the opportunity to develop and increase the production of ornamentals, fruits and hardwoods trees for forest projects and farmers to promote initiatives of reforestation and improve quality and varieties of trees in West and Midwest Panama. He expects to graduate with his Master of Science degree with a concentration in Fisheries and Aquaculture in May of 2018, and will begin doctoral research at the Department of Oceanography and Coastal Sciences at Louisiana State University in Spring 2018.