BLUE CRAB POPULATION HEALTH AND HUMAN HEALTH RISK ASSESSMENT IN A MIXED NATURAL AND MAN-MADE HABITAT

Prepared by

PATRICK M RITCHIE

A TECHNICAL PAPER PRESENTED TO THE SOIL AND WATER SCIENCE DEPARTMENT OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Technical Paper Presented to the Soil and Water Science Department
of the University of Florida in Partial Fulfillment of the Requirements for the
Degree of Master of Science

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By Patrick M Ritchie

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A blue crab, *Callinectes sapidus,* population in a mixed natural and man-made habitat of the White Lake watershed located in Vermilion Parish, Louisiana was evaluated for animal health and human consumption. The natural waterways and waterbodies of south Louisiana create a massive network interconnected with man-made canals providing habitat for blue crab propagation and persistence. A field study was conducted in December 2010 and January 2011 to determine if the conditions in White Lake, Schooner Bayou, and a number of man-made canals were conducive to blue crab habitat. A total of 307 crabs were caught from 23 locations. Crab carapace width, length, weight, and sex were measured. Crabs were further evaluated for total and individual muscle, exoskeleton, hepatopancreas, other soft tissue weight. Water chemistry including temperature, electrical conductivity, pH and DO were measured at each crab sampling location. Blue crabs sold from markets along the Gulf Coast were also purchased and submitted for laboratory measurements of total and individual tissue weight. A laboratory study was conducted in the same man-made canals by the Louisiana Department of Health and Hospitals to evaluate the human health risk from total arsenic and barium exposure associated with consuming blue crabs. The average total tissue weight was 178.35 g, average carapace width was between 15.1 cm to 18 cm, and average catch per unit effort was 4.32

pounds/trap day for crabs collected in the White Lake watershed in this study. The results of this study indicate that the blue crab population is robust and healthy with individuals of expected width, length, and weight compared to markets across the Gulf Coast. The human health risk assessment concluded that total arsenic and total barium exposure levels are expected to be safe for human consumption at concentrations detected in this study.

CHAPTER 1

INTRODUCTION

The blue crab, *Callinectes sapidus,* is an ecologically, economically, and culturally significant species to South Louisiana and the United States Gulf Coast. The ecological significance of blue crab is due to its role as a key benthic predator in inland and coastal waters by controlling abundance, diversity, and structure of various benthic communities (Virnstein 1977, 1979). The economic significance of blue crab to commercial fishing is substantial to Louisiana and the United States. According to the National Marine Fisheries Service report, Fisheries Economics of the United States 2012, Louisiana caught more blue crabs in 2012 than any other state in the U.S. at 45 million pounds and earning over $43 million for fisherman. The report also highlights that blue crabs contributed to 14% of total shellfish landings in the country. The cultural significance in Louisiana is paralleled with the ecological and economic impact on Louisiana. Fishing is a way of life for many communities and the cultural importance is seen throughout the state of Louisiana in the numerous festivals and fairs dedicated primarily to seafood and blue crab.

Blue Crab

The blue crab, *Callinectes sapidus,* is an abundant, rapid developing marine crustacean distributed along the Gulf of Mexico and the east coast Atlantic Ocean waters. The blue crab habitat includes a variety of water body types due to the developmental stages and migratory patterns throughout its life. Upper, middle, lower estuaries and adjacent marine environments provide ideal water quality conditions along the U.S. Gulf Coast (Perry and McIlwain, 1986). In Louisiana, blue crab habitat includes inland and coastal waters. The structure of Louisiana

inland and coastal waters is a combination of natural and man-made waterways and waterbodies.

Blue Crab Habitat

Natural Waterways and Waterbodies

The Gulf of Mexico along coastal Louisiana includes intertidal areas that are less than 20 m deep and extends south to areas of the continental shelf reaching depths of 180 m (Gore, 1992). The area is dominated by thick sediments deposited from natural waterways that discharge into the Gulf along Louisiana. Coastal Louisiana is divided into 9 drainage basins (from west to east): Calcasieu/Sabine, Mermentau, Teche/Vermilion, Atchafalaya, Terrebonne, Barataria, Mississippi Delta, Brenton Sound, and Pontchartrain (CWPPRA, 2015).

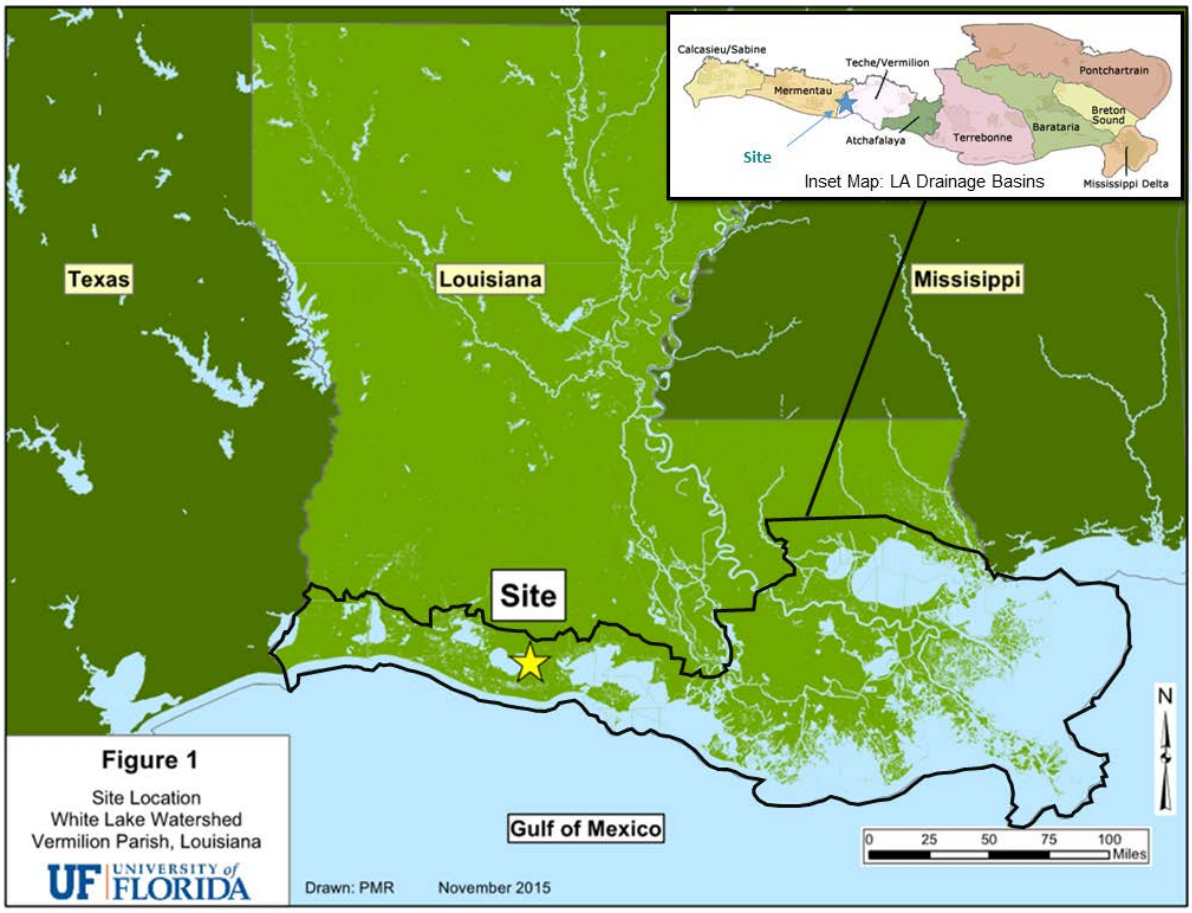

Figure 1: Louisiana drainage basins and site location map

Natural waterways that are interconnected and discharge to the Gulf of Mexico that provide migratory pathways to inland waterways, waterbodies, and wetlands include the Mississippi River, Barataria Waterway, Bayou Lafourche, Houma Navigational Canal, Lower Atchafalaya River, Wax Lake Outlet, the Gulf Intracoastal Waterway and many more. Blue crabs use these migratory pathways throughout their lifespan to search for productive habitats and mates.

Man-made Waterways and Waterbodies

The natural waterways and waterbodies throughout south Louisiana create a massive network interconnected with man-made canals providing habitat for blue crab propagation and persistence. The energy industry built the majority of man-made waterways in Louisiana for oil and gas rig access. Canals were dredged through coastal wetland to depths of 2.4 m to 3.0 m deep, 20 m to 40 m wide, and ranging in length from 100 m to 2000 m with a characteristic "keyhole" shape (Davis, 1973, Neill and Turner 1987). Additionally, canal creation was promoted by the federal government for inter and intrastate commerce, to increase inland transportation, to stimulate private enterprise, to provide strategic local connections, and to benefit national interest (Alperin, 2001). Commercial and recreational fisherman fish these canals due to the structural habitat characteristics in the canals that are beneficial for aquatic organisms.

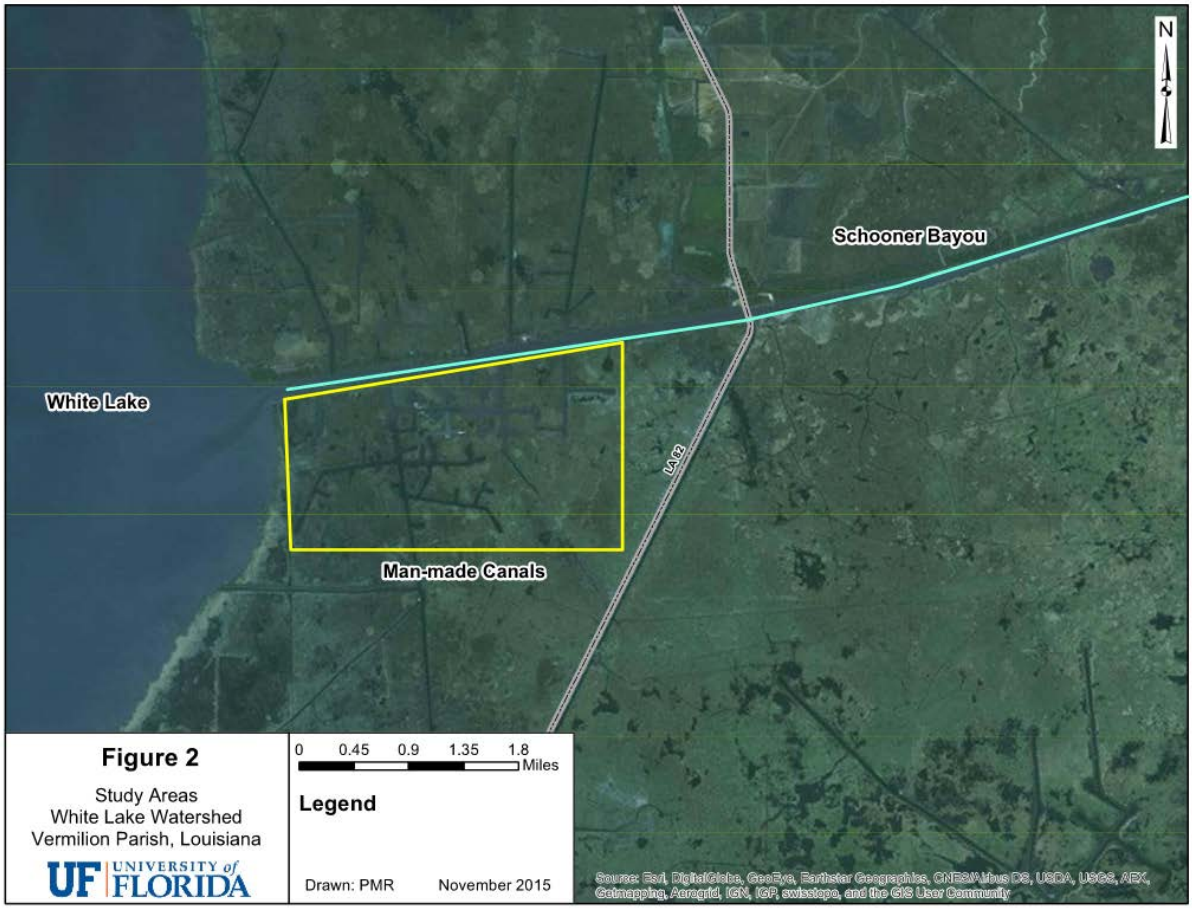

Figure 2: Areas of investigation. The Schooner Bayou is highlighted in light blue, the man-made canals are located within the yellow box, and White Lake is at the western most extent of the map.

Habitat Distribution of Blue Crab

Blue crab habitat varies based on life stage and environmental conditions. The 7 to 8 blue crab larval stages occur along the coastal shelf in the Gulf of Mexico until post-larva development of the megalopa stage (Orth and van Montfrans, 2002). The Megalopae migrate to coastal bays and estuaries (Rabalais et al. 1995, van Montfrans et al. 1995) and settle into shallow nursery habitats such as marsh and seagrass beds (Zimmerman and Minello 1984, Orth and van Montfrans 1990, Heck and Coen 1995). Later-stage juveniles and adults re-distribute to different habitats based on size, sex, molt stage, salinity, and food availability (Hines et al. 1987, Mansour & Lipcius 1991). Based on these life stage requirements, the available habitat for blue crabs includes a mix of natural and man-made waterways and waterbodies along coastal and inland Louisiana.

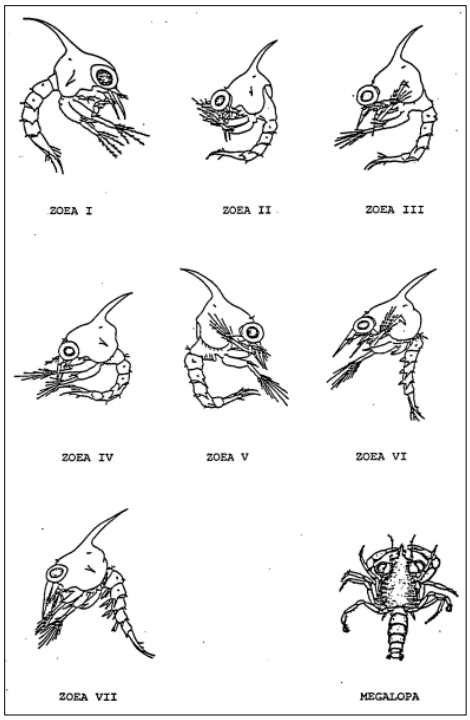

Figure 3: Blue crab larval stages (Costlow Bookhout, !959)

Water Chemistry Criteria of Blue Crab Habitat

Developmental Stage Salinity Regime

The blue crab undergoes a number of developmental stages through its life cycle. Each stage of development occurs in a typical salinity regime, season, and habitat. Sexually mature crab copulation typically occurs in late summer, followed by the migration of the inseminated females in fall to high salinities to incubate their eggs (Hines, 1987). Females will mate in the

soft-shell state following the pubertal or terminal molt and be carried by the male until her shell hardens, which usually occurs in the spring and summer (Perry and McIlwain, 1986). Blue crab life-cycles are marked with rapid growth and dynamic seasonal fluxes. Along the Gulf Coast, egg-bearing females will be found in northern Gulf of Mexico waters and in estuaries with spawning occurring in the spring, summer, and fall (Gunter 1950, Daughtery 1952, More, 1969, Adkins, 1972, Perry 1975). Blue crab hatchings are sensitive to low salinities with ideal salinity conditions between 18 to 29 parts per thousand (ppt) (Sandoz and Rogers, 1944). Once spawning occurs, blue crab undergo 7 to 8 zoeal stages within 31 to 49 days and one mealopal stage from 6 to 20 days of development in saline waters greater than 20.1 ppt (Perry and McIlwain, 1986). Following the larval stages, juvenile crabs migrate and inhabit a range of salinity regimes with the most abundant distribution found in middle and upper estuarine waters with salinities less than 5.0 ppt (Perry and McIlwain, 1986). The migration of blue crabs relates to environmental conditions, season, and life cycle stage. For successful development of blue crabs, salinities in excess of 20.0 ppt are required (Perry and McIlwain, 1986). Once development and migration are completed, adult crabs are found along a wide range of water quality conditions, with males being more tolerant of freshwater and females preferring higher salinities. The tolerance to and requirement of a variety of salinity regimes contributes to blue crab distribution along the Gulf Coast.

Water Temperature Effect on Maturation Size

Blue crabs are decapod crustaceans which undergo molting of the exoskeleton reinforced with calcium carbonate to increase in size as they age (Hines et al., 1987). Temperature strongly affects the growth of blue crabs and length of time required to reach maturity, which is approximately 1 year in the Gulf of Mexico (Perry, 1975 and Tatum, 1980). Size is determined by measuring the width from the lateral spines of the carapace (Figure 4).

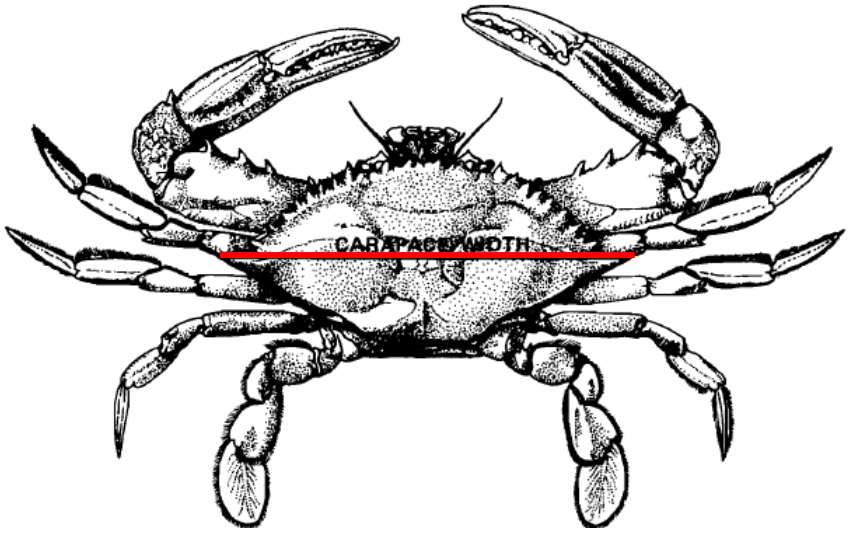

Figure 4: Carapace Width Measurement Rathbun 1930

Leffler (1972) conducted a laboratory analysis demonstrating that molting rate increased rapidly with increasing temperatures from 13.0 to 27.0 C, however the increase continued at a slower rate between 27.0 to 34.0 C (Leffler, 1972). In colder waters with temperatures below 13.0 C, blue crab growth virtually ceased (Perry and McIlwain, 1986). Cunningham also conducted a laboratory analysis of early juvenile crabs (~2.5-16 mm carapace width) within 6 different salinity and temperature treatments and determined that juvenile crabs in higher water temperatures had a decreased intermolt period (IMP) and a decrease in growth per molt (Cunningham 2015). However, Tagartz observed blue crabs in water temperatures between 13.8 to 32.1 C and suggested that temperature does not influence growth per molt in field studies as opposed to laboratory conditions (Tagartz, 1968).

Although there is some disparity between field observations and laboratory studies, the predominate factors contributing to population health and distribution of blue crabs include substratum, food availability, available shelter, water temperature and salinity (Perry and McIlwain, 1986).

Dissolved Oxygen Requirements

Dissolved oxygen concentrations in water vary based on aquatic species, detritus, depth, salinity, temperature, pollutants, and pH. Dissolved oxygen concentrations also vary seasonally. Summer months are associated with greater primary production which in turn increases decomposition of organic matter which consumes dissolved oxygen. Dissolved oxygen variations may occur naturally or through anthropogenic nutrient loading to waterways. There is increased mortality and alteration in migratory habits of blue crabs caused by low levels of dissolved oxygen (Perry and McIlwain, 1986).

US EPA has designated criteria to protect the survival, growth and propagation of balanced, indigenous populations of ecologically, recreationally and commercially important fish and shellfish species inhabiting deep-water habitats (Appendix A; U.S. EPA 2003a). Seasonal, expansive hypoxic/anoxic conditions are well known in the Gulf of Mexico and have been observed in 32 of the 38 estuaries by Bricker (1997) (Turner and Rabalais, 1994). EPA conducted a study from 2001-2005 to identify molecular indicators of dissolved oxygen stress in crustaceans. The study identified dissolved oxygen levels for severe hypoxia (1.5 ppm DO), moderate hypoxia (2.5 ppm DO), and normoxia (8 ppm DO) and identified genetic markers in blue crabs that are exposed to chronic, intermittent, and cyclic hypoxia (EPA, 2001). Criteria are difficult to establish due to the complexity of dissolved oxygen compared to other known contaminants.

pH Sensitivity

The water pH affects blue crabs physiologically and behaviorally. Water pH may be affected by many natural and anthropogenic stimuli. As discussed in the section on dissolved oxygen, the Gulf of Mexico is known to become hypoxic, particularly along the coastal and

estuarine waters that the blue crab inhabits. A decrease in pH, associated with hypoxic conditions, is suggested to decrease phenoloxidase activity which is involved in the ability of crustaceans to remove culturable bacteria from their hemolyph and defend themselves against microbial pathogens (Tanner, 2006).

Blue crab migratory patterns and habitat range may be altered when pH conditions become unfavorable. Laughlin et al. (1978) demonstrated in laboratory assessments that blue crab avoidance occurred in acidic water with pH ranging from 4.6 to 5.8. However Laughlin et al. (1978) field studies have also demonstrated contrary findings to laboratory conditions; where smaller blue crabs were in abundance during long-term assessments with low pH.

Constituents of Concern for Blue Crab Consumption

Blue Crab Consumption

Blue crabs caught from south Louisiana are consumed across the United States, particularly along the Gulf Coast and in areas of the northeast around the Chesapeake Bay. Consumption habits are quite difficult to obtain and vary relative to race, religion, economic status, and location. The Louisiana Department of Health and Hospitals (LDHH) protocol dictates that interviews, creel surveys, and/or needs assessments of anglers may be performed to determine the species and sizes which are commonly consumed in an area. A survey conducted in 2006 by the University of Louisiana at Lafayette Center for Socioeconomic Research found blue crab consumption percentages by respondents from lower Bayou Lafourche, located east of the study area (Gramling et al. 2006).

How often respondents eat or use blue crab in cooking	Percentage
More than once a week	4%
Weekly	19%
Monthly	34%
Seldom	21%
Once a Month	58%

Table 1 **:** The percentages may total over 100% since species are used in several ways (direct consumption, cooking, etc.) Gramling et al. 2006.

The survey is helpful in understanding and supporting the idea that blue crab consumption and use in cooking is prevalent in South Louisiana. However the survey lacks the amount of blue crab consumed or the physical characteristics (sex, age, weight, etc) of the consumer.

In the absence of site-specific consumption data, LDHH estimates adult and child consumption rate and frequency of 30 grams and 15 grams per day for 365 days per year respectively (LDHH, 2012). The following is an example of calculating human blue crab consumption for the purposes of human health risk assessment:

> *One average sized crab has 2 oz of meat and 0.5 oz of hepatopancreas (part of the digestive system which produces digestive enzymes and is responsible for filtering impurities from the crab's blood, also often referred to as "tomalley"). Therefore, an 8 oz meal of crab meat would consist of 4 crabs - and if the hepatopancreas is consumed, the meal would also include 2 oz of hepatopancreas (0.5 oz x 4 = 2 oz) The default consumption rate for hepatopancreas is 7.5 g/day, which equates to four*

two-ounce servings/month (2 ounces of hepatopancreas / 8 ounces of crab meat). (NJDEP, 2002).

Arsenic

Arsenic is a naturally occurring element found in soil, sediment, groundwater, and surface water**.** Seafood is major source of arsenic in the diet of people in south Louisiana. The primary forms of arsenic found in seafood are organic forms of arsenic – arsenobetaine and arsenocholine. These organic compounds of arsenic are essentially nontoxic to humans, unlike inorganic arsenic (ATSDR, 2007a). The inorganic forms of arsenic are established as carcinogens and would be expected to present human health risk if present in seafood tissues. (ATSDR, 2007a, EPA, 1988).

Barium

The environmental fate and transport of barium is determined by several biogeochemical conditions including pH, cation exchange capacity, and availability of anions. Barium is used in a wide variety of commercial products, processes, mining and refining operations including use in metal alloys, fireworks, ceramic and glass making, dyes bleaches, electronics, rat poison, and in the oil and gas industry (USEPA, 2005a). The potential absorption by plants and animals is determined by the solubility of barium and the specific barium compounds. Exposure to soluble barium compounds (barium chloride, barium nitrate, barium hydroxide) and the Ba^{+2} ion are a greater concern to human health and the environment than the insoluble forms of barium which are not toxic (USDHHS, 2007). The Ba^{2+} ion has the potential to mimic calcium functions by being incorporated during the molt of blue crabs and into the exoskeleton (USDHHS, 2007, LDHH, 2011).

Objectives and Hypothesis

Objectives

The purpose of this research is to investigate water chemistry in the White Lake watershed, which includes a mix of natural and man-made waterways and waterbodies, and supports a healthy blue crab population that is safe for human consumption. Louisiana is home to a great deal of marine recreation and industrial and energy infrastructure that coexists with the blue crab habitat. The project site for this study includes man-made canals supporting industrial and energy infrastructure, Schooner Bayou, and White Lake, located in Vermilion Parish, Louisiana. The constituents of concern (COC) for this research will include those that are commonly associated with these activities including the metals, arsenic and barium. The research will provide the methods used to catch, measure, and analyze the population health of the blue crabs. Surface water chemistry measurements were collected at each fishing site and will be compared to ideal water chemistry for healthy crab habitat. The Louisiana Department of Health and Hospitals (LDHH) conducted a similar study of blue crabs at the study area coinciding with the research conducted by the author and others. The conclusions of the LDHH study will be presented demonstrating the safe consumption of blue crabs from the study area.

Hypotheses

- The population of blue crabs (*Callinectes sapidus*) in the White Lake watershed assessed by the research team in 2010 and 2011 is healthy and robust with individuals of expected size and weight.
- The blue crabs (*Callinectes sapidus*) caught in the White Lake watershed are comparable in tissue weight to market crabs purchased along other areas of the Gulf Coast.
- The water quality recorded in man-made canals supporting industrial and energy infrastructure, Schooner Bayou, and White Lake supports blue crabs (*Callinectes sapidus*) at expected abundance determined by catch per unit effort.
- The blue crabs (*Callinectes sapidus*) in the White Lake watershed are safe for human consumption as determined by the Louisiana Department of Health and Hospitals.

CHAPTER 2

MATERIALS AND METHODS

Study Area

The site, located in Vermilion Parish, Louisiana, is about five miles southwest of Forked Island and 50 miles southwest of Lafayette, the state's fourth largest city. The areas of interest are mixed natural and man-made waterways and waterbodies. The study area is divided into three main areas of investigation: White Lake, Schooner Bayou (old Intracoastal Waterway), and other man-made canals The study area is used for recreational and commercial fishing and trapping, hunting, fish and wildlife habitat, agriculture, oil and gas production and includes a number of oilfield canals and energy production facilities.

The study area is fully contained within the Mermentau River Basin and for the purpose of this report will be generally described as the White Lake watershed.

Man-made Canals

The study area includes private, man-made canals located in Sections 15, 16, and 17, Township 15 South, Range 1 East in Vermilion Parish, Louisiana. Man-made canals are utilized for energy production activities, recreational and commercial fishing, hunting, and trapping.

White Lake

White Lake is a large natural lake (56,000 acres) in the coastal marshes within the Mermentau River basin. White Lake is generally turbid and shallow (average depth 5 feet) and is positioned 1.2 feet above mean sea level by controlled water flow through the Schooner Bayou Locks located approximately 7.5 miles to the east (LDWF, 2013).

Schooner Bayou

Schooner Bayou (old Intracoastal Waterway) is a man-made canal. East of the study area is the Schooner Bayou Locks, a lock-gate control structure constructed in the 1950's by the U.S. Army Corps of Engineers to conserve fresh water in the lake sub-basin by maintaining normal to above normal lake stages, agricultural purposes, prevent uncontrolled tidal inflow during agriculture irrigation season (April – August), and maintain minimum water levels for navigation (LDWF, 2013).

Market Crabs

Reference data for the study area was collected by purchasing blue crabs from six retail fish markets in the Gulf Coast region: Baton Rouge, Des Allemands, Lake Charles, Biloxi, New Orleans, and Houston. The market workers provided information regarding the water body source of the crabs. The Baton Rouge market indicated the crabs were caught in bayous and waterbodies around Dulac, Lousiaiana. Des Allemands' market crabs were caught in Lac Des Allemands. Lake Charles' market crabs were caught in Calcasieu Lake. Biloxi market crabs were caught in the Gulf of Mexico off the coast of Mississippi. New Orleans market crabs were caught in Lake Pontchartrain. Houston market crabs were caught in Galveston Bay. All seafood markets contacted in Lafayette indicated that White Lake was the source of blue crabs, thus no market crabs were evaluated from this market.

Site Descriptions

Crabs were collected in man-made canals, White Lake, and Schooner Bayou from 23 locations (Figure 5). Sufficient sampling locations were included in this study to permit valid comparisons and evaluations if blue crabs were not caught at some locations. The number of locations were selected after consultation with the local crab fisherman to ensure the laboratory required volume (estimated to be 5 crabs) was collected from waterways and waterbodies that were used by commercial fisherman within the White Lake watershed.

Man-made Canals

Crabs were collected in the man-made canals from 13 locations. Additionally, the LDHH collected crabs from 9 locations. Canal depths varied between locations, ranging from 2 feet to 8 feet deep. Sample identification for the man-made canal samples are T-01 through T-12 and EWL-1 through EWL-9, for our study and the LDHH study respectively.

White Lake

Crabs were collected in the eastern portion of White Lake from 4 locations. Water level in White Lake is managed by the Schooner Bayou Locks with an average depth of 5 feet with an estimated maximum depth during sampling of 8 feet. Sample identification for White Lake samples are TR-06 through T-09. There were no crabs collected in White Lake for the LDHH study.

Schooner Bayou

Crabs were collected in Schooner Bayou, between White Lake and the Schooner Bayou Locks from 6 locations. Schooner Bayou is dredged and managed as a navigable waterway with an estimated maximum water depth of 20'. Sample identification for Schooner Bayou

samples are TR-01 through T-05. There were no crabs collected in Schooner Bayou for the LDHH study.

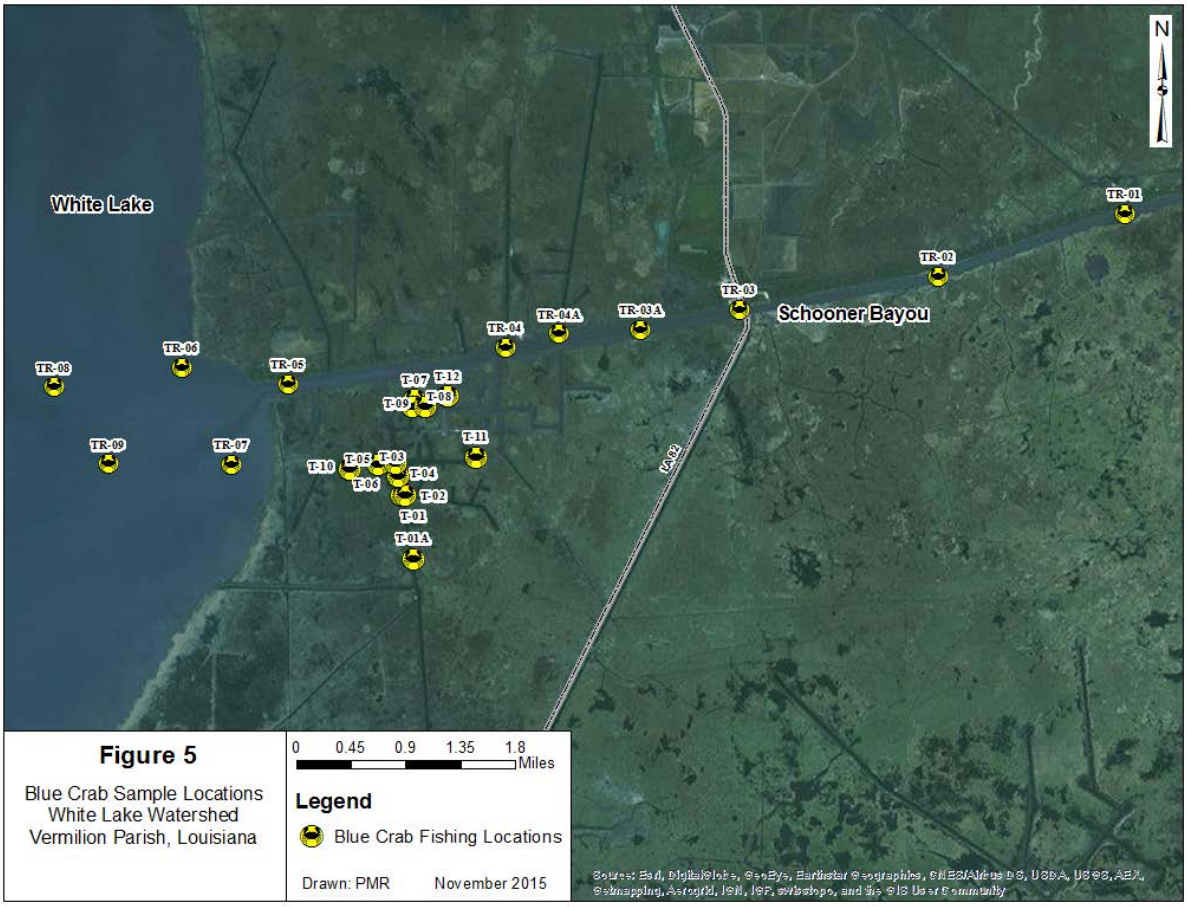

Figure 5: Blue crab sample locations.

Market Crabs

Between 5 and 14 crabs were purchased from each of 6 market locations in the Gulf Coast region (Figure 6). The minimum number of blue crabs required for purchase was 5 individuals and the variability between market samples purchased was based on the sale criteria for each market (i.e. single crab, weight, bushel amount). The information regarding the

specific locations within the named waterbody source and methods used were unavailable for the study. There were no market crabs included in the LDHH study.

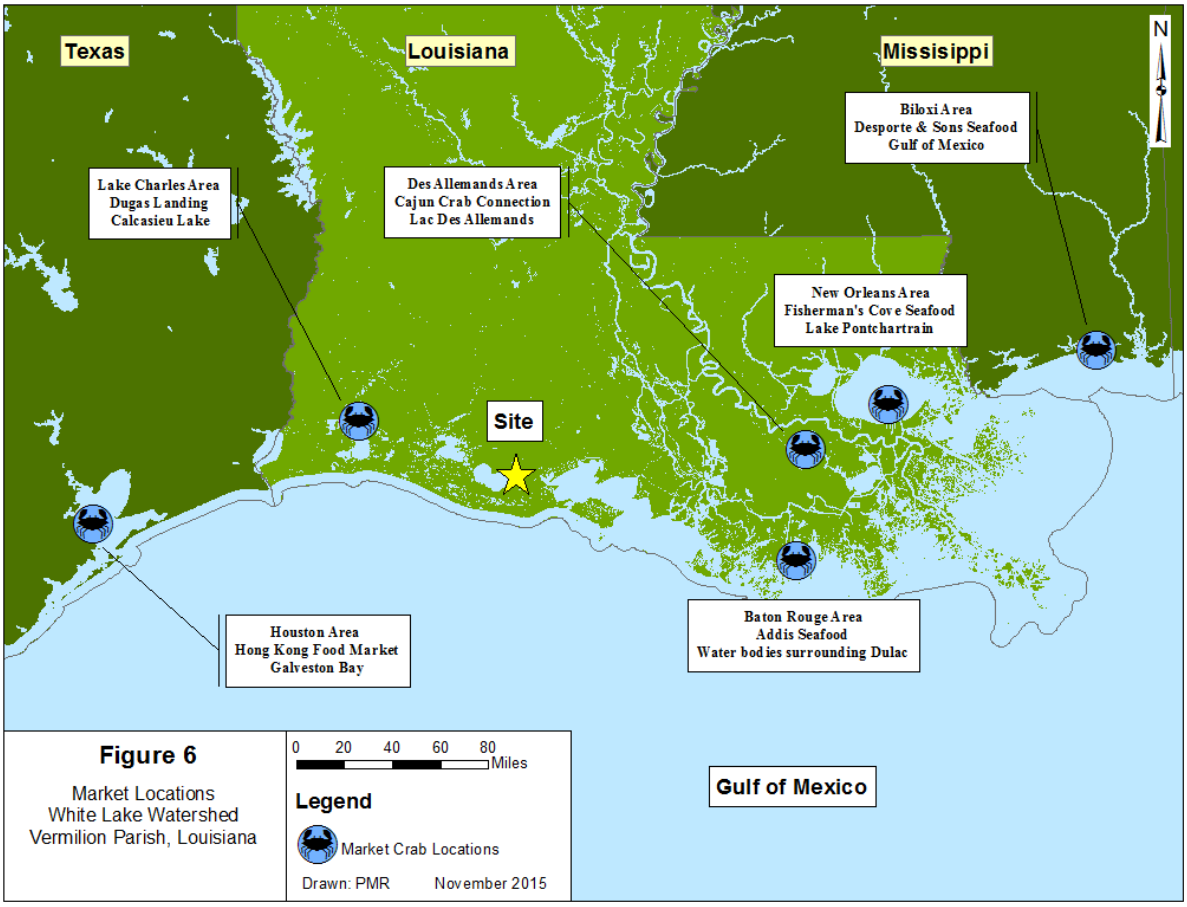

Figure 6: Market crab locations and estimated fishing location based on descriptions from the market.

Materials and Methods

Sampling Design and Rationale

The sampling design and rationale for the project was developed to determine the water chemistry and subsequent habitat health of man-made and natural waterways and waterbodies for blue crabs in the White Lake watershed. Crab tissue weight from the study area is compared in this study to 6 different market locations along the Gulf Coast.

The LDHH study is included to complete the human health exposure from consumption of crabs within the study area.

Sample Types

To meet the study objective, this study will include all samples of blue crabs (*Callinectes sapidus*). For the purpose of this study, we did not anticipate capture of soft-shell crabs in the process of molting or females carrying eggs. If caught they would not be included in the data set and returned to the water.

Water Chemistry Measurements

At each location where crabs were collected, water chemistry data was measured using an In-Situ Troll 9500 that had been calibrated that day using In-Situ Inc., Quik Cal Solution. Ambient water chemistry measurements were taken approximately in the middle of the water column at each location which included: dissolved oxygen (DO), temperature, pH, conductivity, oxidation reduction potential (ORP), turbidity, depth, and time of collection. Water chemistry data was recorded in the field logbook and on the field record form.

Sample Collection Methods

Two methods of passive fishing were used to catch blue crabs, the traditional crab trap and hoop net. Both methods of collection were successful, with the crab trap being the preferred method.

Crab Trap Collection Methods

The research team successfully collected crabs using crab traps at all sampling locations. All traps used were constructed according to Louisiana Department of Wildlife and Fisheries (LDWF, 2015) regulations and similar to those used in recreational/commercial operations. The crab traps are wire mesh boxes approximately 30 inches by 30 inches by 15 inches with hinged lids. The wire mesh used in the construction of traps had 1.5-inch square openings to allow smaller organisms to escape and capture the desired sized crabs.

Crab traps were loaded onto the boat by seasoned local contract fisherman and transported to each predetermined sample location, directed by the team with sampling maps. Once a sampling location was selected by the field team, based on the sample location map in the plan, the GPS coordinates were identified by the field team using a DeLorme Earthmate PN-40 GPS and recorded in the field logbook and on Field Record Forms. The most appropriate location for the trap in the selected waterbody or waterway was determined to facilitate crab collection while avoiding obstructions and navigable water routes.

Figure 7: Photograph depicting crab traps loaded on boat ready for deployment

The trap was baited with catfish parts purchased from a local vendor. The local contract fisherman indicated that it was the typical bait used and from the same source as all other commercial fisherman in the White Lake watershed. The bait tissue was submitted for analytical testing of total arsenic and total barium. After the trap was baited, it was thrown into the water and remained there to be checked for crabs the next day. Each crab trap had an identifiable marker buoy that marked the trap as part of the project.

Figure 8: Photographs depicting the baiting and setting of crab traps

If insufficient number of crabs were caught the trap was returned to the water and checked on successive days until adequate crabs were collected at the location. The number of crabs required to be caught at each location was ≥ 5 individuals. A hooked gaffe was used to grab the buoy line connected to the trap. The crab trap would be lifted out of the water by the line and placed on the side ledge of the boat. The crabs were removed by opening a hinged lid on top of the trap that had been secured by a bungee cord. The crabs were shaken out of the trap or removed with clean tongs.

Figure 9: Photographs from the retrieval and checking of a crab trap

Immediately upon being collected, the crabs were counted and recorded on the field record forms as male or female and then put into labeled clean five-gallon buckets. The buckets were labeled with the sample location ID (e.g. T-02) and each bucket had a small amount of ambient water in it with a loosely applied lid (Figure 9).

Figure 10: Photograph of crab collection and separate sites in collection buckets

Hoop Net Collection Method

To meet the study objective, hoop nets were used at 3 locations in the man-made canals in combination with crab traps to increase the likelihood of capture and decrease the collection effort required. Hoop nets are not legal gear in Louisiana waters for harvest of blue crabs and were only used in this study under the scientific collection permit issued by the LDWF (LDWF, 2014). Hoop nets are cone-shaped nets made from vegetable or synthetic materials that is staked to the bottom of the bayou. The netting is stretched over a series of 6 wooden rings or hoops approximately 3 feet in diameter creating a long cylindrical form. At one end of the net there is an opening which connects to a series of throats or flues at each ring allowing fish and shellfish to be captured. Catfish parts were placed in the back of the net to attract blue crabs through the throats to the bait and are unable to exit. The crabs were collected when the net is lifted out of the water.

The hoop nets tested in this project were effective in capturing larger fish such as catfish but were not as effective in catching blue crabs compared to the traps. The three hoop nets yielded a total of 7 crabs for the 10 day field effort and are not included in this study.

Figure 11: Photograph of the hoop net with blue crabs and various fishes

Field Record of Crab Collection

A field record of sampling was completed for each site and passive collection device used. Species were identified upon collection and non-target species were returned to the water. Selected target species were rinsed with ambient water to remove any foreign material from the external surface and placed in buckets filled with ambient water to prevent cross contamination (Levert, 2010). Each blue crab was measured to determine length, width, sex, and wet weight. A calculation was done that combined crab weight, length and width, and is described as crab fullness.

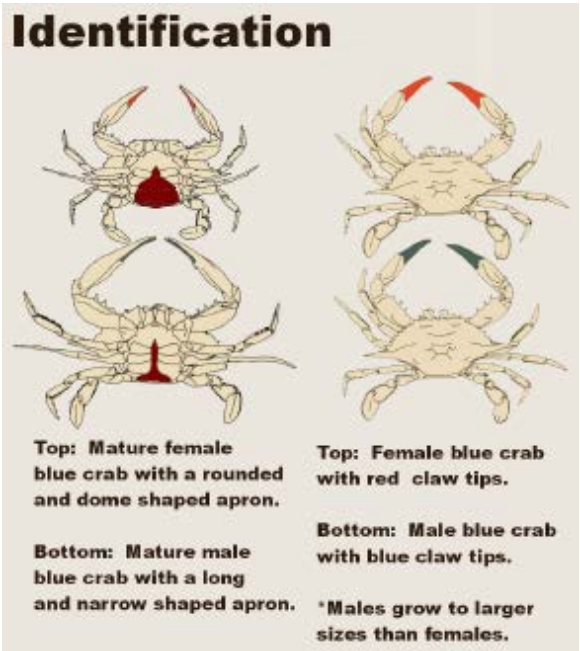

Figure 12: Field identification. Source LDWF 2015

It is average crab weight divided by the length times the width of the crab [g/(cm x cm)] (Connelly, 2010). The crabs were placed on wet ice in a clean cooler dedicated to one sample location. The ice

was double bagged in Ziploc® bags (so excess water would not drown them) and placed around the crabs in order for them to arrive alive at the laboratory. A copy of the completed Field Record Form and Chain of Custody accompanied each sample cooler.

Sample Preparation

Sample preparation was conducted by trained laboratory personnel which included dissection and separation of tissues (muscle, hepatopancreas, exoskeleton, other soft tissues). The tissues were separated and weighed on a wet weight as received basis.

Figure 13: Photograph of blue crab measuring and weighing

Date	Field planning and safety meeting Assemble supplies and equipment	Set crab traps at sample locations	Calibrate water quality instrument and record water chemistry	Check traps for crabs and re-bait traps	Collect crabs from traps	Weigh/measure /package crabs for shipping	Complete field documentation and chain of custody forms - Ship samples overnight to lab
12/13/10	√	Set crab traps at TR-01 through TR-09, and T-01 through T-12					
12/14/10	√		Recorded water chemistry at locations: TR-01, TR-02, TR- 03, TR-03A, TR-04, TR-05, TR-06, TR-07, TR-08, TR-09	Checked traps for crabs at locations: TR-01, TR-02, TR- 03, TR-03A, TR-04 (twice), TR-05, TR-06, TR-07, TR-08, and TR-09	Collected crabs at locations: TR-03A, TR-04, TR-05, TR- 06, TR-07, TR-08, and TR-09	√	Recorded and shipped crabs from locations: TR-03A, TR- 04, TR-05, TR-06, TR-07, TR-08, and TR-09
12/15/10	√		Recorded water chemistry at locations TR-01, TR-02, T- 01A	Checked traps for crabs at locations TR-01, TR-02, T- 01A		√	Recorded and shipped crabs from locations: TR-01 and T- 01A
12/16/10	√	Set hoop nets at locations: T-07, between T-05 and T-06, and T-12	Recorded water chemistry at locations T-09, T-06, T-04, T- 03	Checked traps for crabs at locations T-12, T-09, T-08, T- 07, T-05, T-06, T-10, T-04, T-03, T-02, T-01, T-11, and TR-02	Collected crabs from T-09, T- 06, T-04, and T-03	√	Recorded and shipped crabs from locations: T-03, T-04, T- 06, and T-09
12/20/10	√√ (two meetings)		Measured water chemistry at locations: TR-03, TR-02, T- 12, 08, 10, 06, 05, 04, 02, 01	Checked traps for crabs at: TR-03, TR-02, T-12, 08, 07, 10, 06, 05, 11, 04, 02, 01	Collected crabs from locations: TR-03, TR-02, T-12, 08, 10, 06, 05, 04, 02, 01	√	Recorded and shipped crabs from locations: TR-03, TR-02, T-12, T-08, T-10, T-06, T-05, T-04, T-02, and T-01
12/21/10	√		Recorded water chemistry at locations: T-07, T-05, T-11, T- 02	Checked traps for crabs at: T-07, T-05, T-11, and T-02	Collected crabs from locations: T-07, T-05, T-11, and T-02	√	Recorded and shipped crabs from locations: T-02, T-05, T- 07, T-
1/3/11	√			Checked traps for crabs at: TR-02, TR-03, TR-04 and T-03,T-07, T-08, T-10, and T-12	Collected crabs from locations: TR-02, TR-03, TR- 04 and T-03, T-07, T-08, T- 10, and T-12	√	Recorded and shipped crabs from locations: TR-02, TR-03, TR-04 and T-03, T-07, T-08, T-10, and T-12
Notes: Field activity log includes all tasks completed each day							

Table 2: Field activity log for the collection effort during this study

Louisiana Department of Health and Hospitals Study Methods and Materials

Standard crab traps were deployed by the Louisiana Department of Wildlife and Fisheries for the LDHH study in the man-made canals within the White Lake watershed in response to claims that the blue crabs contained detectable limits of arsenic and barium.

At least 8 crabs were collected by the LDWF from each of the 9 locations on November 23, 2010. No sampling effort data was available to determine the length of time the traps were set for this study. The crabs were removed by hand, rinsed with ambient water, and placed in labelled (date/time of collection, site location, collector's name) clear plastic bags before placing in cooler and transported to the Louisiana Office of Public Health laboratory (LDHH, 2011).

Analytical Protocols for Blue Crab

The analytical protocols for the LDHH study are based on analyses of edible tissues and potential leaching from the cooking process of the exoskeleton. Edible tissue of crabs typically includes all leg and claw meat, back shell meat, and body cavity meat (LDHH, 2012). The crab hepatopancreas was included in analysis due to its typical consumption in south Louisiana. The crab tissues heptaopancreas, and boil water were analyzed separately to enable the evaluation of human health risks associated with consuming these tissues. Soft-shelled crabs were not evaluated in the study area.

Sample Preparation and Rationale

The samples collected at all locations were prepared for analytical analysis using two methods to determine concentrations of total arsenic and total barium in meat and fat in both the raw and boiled state. The first set of composite samples from 4 to 9 crabs were boiled together

using clean tap water similar to the typical method of cooking for crab boils. The tap water was collected prior and post boiling and analyzed for total Arsenic and Barium. Blue crab shell and claws are typically used in cooking gumbo; the analysis of the boil water was used to simulate this usage.

The carapace of the crabs were removed by lifting the telson (posterior flap that covers the gonads) and pulling it off the body. The digestive ceca (hepatopancreas) and gut contents within the body cavity were removed, homogenized, placed in labelled Ziploc® bags, and stored frozen until analysis. Tissues from the body and claws were removed, homogenized, placed in labelled Ziploc© bags, and stored frozen until analysis.

The second set of composite samples from 4 to 9 uncooked crabs were dissected and prepared as described above.

Analytical Methods

The two sets of crab samples were tested using EPA Method 200.8, which provides a procedure for the determination of trace metals using inductively coupled plasma – mass spectrometry (ICP-MS). Sample preparation includes dissection and separation of tissues (muscle, hepatopancreas, exoskeleton, other soft tissues). Tissues are weighed separately. Sample decomposition used acid-microwave assisted digestion, EPA SW 846 3051 method (LDHH, 2011). The total 72 tissue samples and water samples were analyzed for total arsenic and total barium.

Statistical Methods

Statistical analysis for the collection effort, “fullness”, carapace width comparison between habitat types (e.g. lake and man-made canal), and tissue weight in comparison to market crabs were evaluated as follows:

Collection Effort Determination Method

The number of crabs caught on average per area of investigation was calculated by counting the total number of individuals caught in each by area. The total number was dived by the number of times the trap was check and the quotient is divided by the total number of traps in each area to produce a value weighted average.

$$\boldsymbol{AOI\ weighted\ Average} = \frac{\left(\frac{\boldsymbol{total\ \#\ of\ crabs}}{\boldsymbol{total\ \#\ of\ times\ trap\ checked}}\right)}{\boldsymbol{total\ \#\ of\ traps}}$$

Catch Per Unit of Effort

Data used to determine catch per unit of effort (CPUE) from the White Lake watershed are compared to commercial catch in Louisiana. CPUE is the quotient of the total pounds of crab caught each day and the total number of traps used on that day. The total weight of blue crabs was converted from grams to pounds and input into the formula for each collection day.

$$\boldsymbol{CPUE} = \frac{\boldsymbol{total\ pounds\ caught\ on\ day\ x}}{\boldsymbol{number\ of\ traps\ used\ on\ day\ x}}$$

X = specific collection day

Fullness Determination Method

"Crab fullness" combines crab size and weight and is used to specify the robust nature of the individual crabs. It is calculated as the crab weight in grams divided by the product of the crab carapace length in centimeters and crab width (measured from mouth to abdominal segment) in centimeters.

$$\boldsymbol{Crab\ Fullness} = \frac{\boldsymbol{total\ weight\ weight}}{\boldsymbol{carapace\ length} * \boldsymbol{total\ width}}$$

Carapace Width Comparison Determination Method

The carapace width is used to determine the size distribution of blue crabs. The arithmetic mean, mode, maximum and minimum carapace width will be determined and presented for each of the three habitat types. The statistical software ProUCL 5.0.00 for Environmental Applications for Data Sets with and without Nondetect Observations was used to determine the 95% upper confidence limit of the carapace width.

Tissue Weight Comparison Determination Method

The Wilcoxon test is used to compare the total tissue weight from the 6 market crab locations to the total tissue weight of the blue crabs caught in the White Lake watershed. The Wilcoxon test is used for data that is not normally distributed or if the variances for the two conditions are markedly different.

Reference Dose for Ingestion of Food

The US EPA has outlined the equation to determine the amount (mg/kg-per day) of food ingested for a typical individual in the United States.

$$Intake = \frac{CF * IR * FI * EF * ED}{BW * AT}$$

CF = Contaminant concentration in food (mg/kg)

IR = Ingestion rate (kg/meal)

FI = Fraction ingested from contaminated source

EF = Exposure frequency (meals/year)

ED = Exposure duration (years)

BW = Body weight (kg)

AT = Averaging time (days)

This equation will be used for the consumption of blue crab tissue and hepatopancreas ("fat") for both total arsenic and total barium from the White Lake watershed. The analysis will include both the tissue and fat determination for 30 and 70 years of consumption as boiled and raw tissues.

CHAPTER 3

RESULTS AND DISCUSSION

The sampling team worked ten days in order to collect a sufficient number of crabs to satisfy the requirements of this study. This involved checking crab traps a total of 51 times to collect a total of 307 crabs from the 23 sampling locations. The level of effort varied between the three areas of investigation.

The four traps in White Lake had sufficient number of crabs after one day of deployment.

Crab Habitat	WHITE LAKE				Totals and Averages
Sample Location ID	TR-06	TR-07	TR-08	TR-09	
Total Number of Crabs per Location	5	11	10	11	37
Number of Times Trap Was Checked	1	1	1	1	4
Average Crab Weight (g)	231	240	218	245	233
Average Crab Width (cm)	16.2	17.2	17.3	17.5	17.1
Average Crab Length (cm)	7.1	7.1	7.2	7.5	7.3
Average Crab Fullness (g/cm^2)	2.0	1.9	1.7	1.8	1.9

Table 3: Collection effort and field measurements of blue crabs in White Lake

The 13 traps in the man-made canals required between 1 and 4 visits to satisfy the required number of crabs for this study.

Crab Habitat	MAN-MADE CANALS													Totals and Averages
Sample Location ID	T-01	T-01A	T-02	T-03	T-04	T-05	T-06	T-07	T-08	T-09	T-10	T-11	T-12	
Total Number of Crabs per Location	11	15	28	17	12	17	18	14	13	5	17	8	14	189
Number of Times Trap Was Checked	2	1	3	2	2	3	2	4	3	1	3	3	3	32
Average Crab Weight (g)	206	223	222	214	228	210	204	212	255	184	212	226	190	216
Average Crab Width (cm)	15.6	16.6	16.5	16.4	15.8	16.0	15.9	16.2	17.0	16.2	15.9	16.5	15.4	16.2
Average Crab Length (cm)	6.8	7.2	7.1	6.9	7.1	6.9	6.8	7.1	7.3	6.8	6.9	7.2	6.6	7.0
Average Crab Fullness (g/cm^2)	1.9	1.9	1.9	1.9	2.0	1.9	1.9	1.8	2.0	1.6	1.9	1.9	1.8	1.9

Table 4: Collection effort and field measurements of blue crabs in man-made canals

The 6 traps in Schooner Bayou required between 1 and 5 visits to satisfy the required number of crabs for this study. Once the required number of crabs was collected from a sample location, the traps were removed.

Crab Habitat	SCHOONER BAYOU						Totals and Averages
Sample Location ID	TR-01	TR-02	TR-03	TR-03A	TR-04	TR-05	
Total Number of Crabs per Location	11	15	14	12	18	11	81
Number of Times Trap Was Checked	2	5	3	1	3	1	15
Average Crab Weight (g)	207	169	171	186	207	235	194
Average Crab Width (cm)	16.0	15.1	15.4	16.0	15.8	18.0	16.0
Average Crab Length (cm)	7.0	6.4	6.5	6.7	6.7	7.3	6.7
Average Crab Fullness (g/cm^2)	1.8	1.7	1.6	1.7	1.9	1.8	1.8

Table 5: Collection effort and field measurements of blue crabs in Schooner Bayou

The number of crabs collected per location ranged from five crabs (TR-06 and T-09) to 28 crabs (T-02). The value weighted average per area of investigation was calculated to determine the abundance of crabs at each habitat type. The average number of crabs caught per visit was 6.90 for the man-made canals, 7.85 for Schooner Bayou, and 9.25 for White Lake. White Lake was the most successful fishing location which required only a single visit to each trap to catch the required number of crabs for analysis.

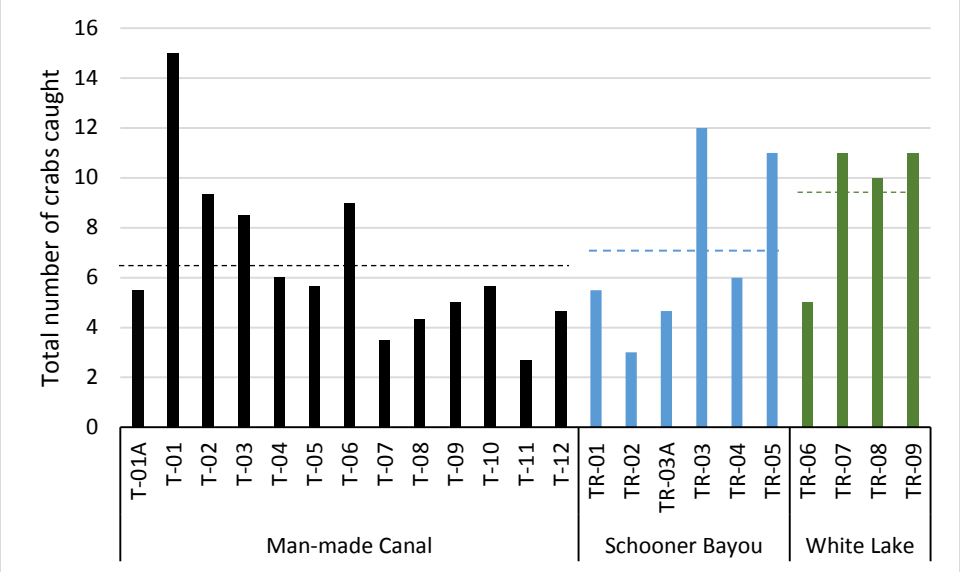

Figure 14: Total number of crabs caught per area of investigation

The catch per unit of effort (CPUE) was calculated for the six days of crab collection from the natural and man-made habitats of the White Lake watershed.

DATE	TOTAL CPUE	SB CPUE	WL CPUE	MM CPUE
12/14/2010	4.63	4.43	4.78	No Catch
12/15/2010	6.19	5.01	No Catch	7.37
12/16/2010	2.49	No Catch	No Catch	2.49
12/20/2010	3.33	2.34	No Catch	3.58
12/21/2010	4.66	No Catch	No Catch	4.66
1/3/2011	4.61	3.90	No Catch	5.04

Table 6: CPUE (pounds/trap day) SB-Schooner Bayou; WL-White Lake; MM-man-made canals

The Total CPUE for the three habitats range from 2.49 pounds/ trap day to 6.19 pounds/ trap day with an average of 4.32 pounds/trap day. White Lake has the highest average CPUE of 4.78 pounds/trap day of the three habitats followed by the man-made canals and Schooner Bayou at 4.63 and 3.92 pounds/ trap day, respectively.

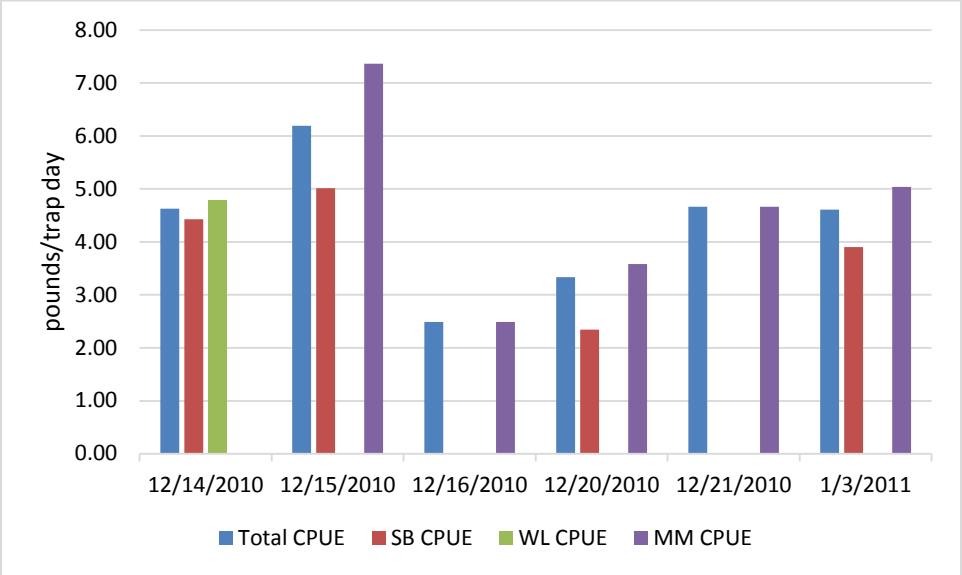

Figure 15: Catch per unit effort

The size structure of the blue crabs sampled from a mix of natural and man-made waterways and waterbodies is compared in this study to the commercial crabbing regulatory

size limit (12.7 cm) and max size (27.94) determined by the LDWF (2015). The Louisiana Department of Wildlife and Fisheries regulation on size for hard shell blue crabs caught is due to the fact that approximately half of the population has reached sexual maturity at this size (LDWF, 2015). The average carapace width from the man-made canals, Schooner Bayou, and White Lake ranged between 15.4 cm and 17 cm, 15.1 cm and 18 cm, and 16.2 cm to 17.5 cm respectively. The carapace width mode from the man-made canals, Schooner Bayou, and White Lake ranged between 14.5 cm and 16.5 cm, 13.5 cm and 18.5 cm, and 16.5 cm to 19.0 cm respectively. The maximum width of blue crabs caught was 20 cm and crabs of this size were present at five locations within all three areas of investigation: T-05, TR-03, TR-04, TR-05, and TR-07. The minimum width of crabs caught was 12 cm, and this was at one single location, T-01 from the man-made canals. Crabs below regulatory limit of 12.7 cm were also caught at TR-02 (12.5 cm) and TR-04 (12.5 cm) from Schooner Bayou. The study was conducted under a LDWF Scientific Collection Permit which exempted us from the commercial crabbing regulatory size. All crabs caught, regardless of size, were included in the study.

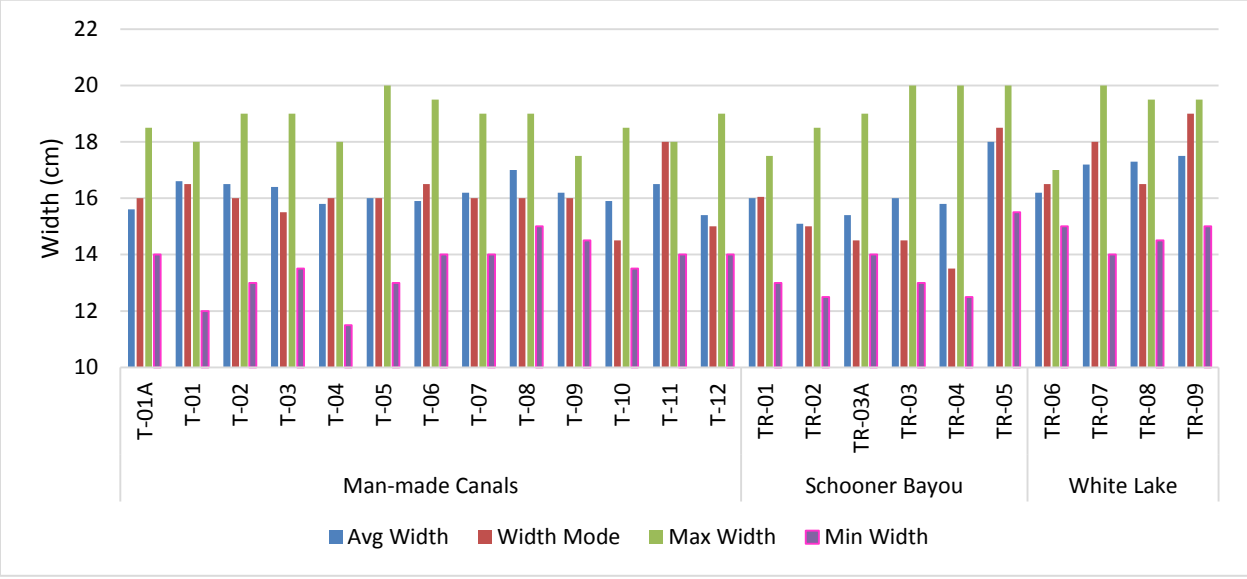

Figure 16: Blue crab field measurement statistics per area of investigation

The three habitat types were evaluated for 95% UCL. The results for White Lake, Schooner Bayou, and man-made canals were 17.57 cm, 16.35 cm, and 16.34 cm respectively.

Blue Crabs were purchased from six markets along the Gulf Coast. The crabs were dissected and the tissues were weighed on a wet weight basis and compared to crabs within the study area. The tissues included the exoskeleton, muscle, hepatopancreas, and other soft tissue. The average total tissue weight from the three areas of investigation were compared to the six market locations. The Houston market had the highest average total tissue weight of 217.89 g and the lowest average of all markets and study area crabs was Baton Rouge at 125.57 g. The Wilcoxon‘s test statistic was applied to the average tissue weight of the 6 markets compared to the average tissue weight of the White Lake watershed (178.35 g). The test statistic is greater than the critical value for the two tailed significance test at 0.05 for the 6 market crab tissue weight measurements providing sufficient evidence to suggest that there is no difference between the tissue weight of blue crabs from the White Lake watershed and blue crabs from the retail markets. The average total tissue weight from the White Lake watershed (178.35 g) is not significantly different than the market crabs and is greater than the average total tissue weight of 5 of the 6 markets.

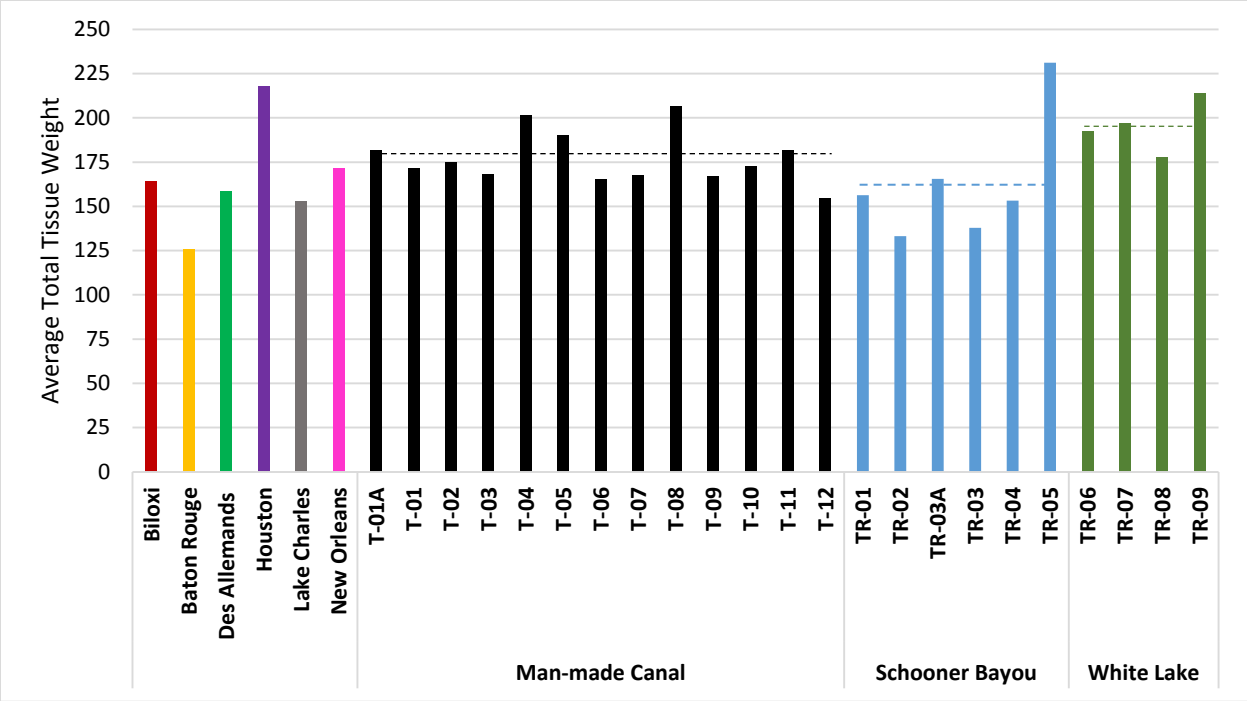

Figure 17: Average total tissue weight comparison by sample location

Table 7: Tissue weight and count of blue crabs from White Lake watershed and markets

AOI	Location	Total tissue wgt (g-ww)	Hepatopancreas wgt (g-ww)	Muscle wgt (g-ww)	Other soft tissue wgt (g-ww)	Exoskeleton wgt (g-ww)	No of Crabs
Market	EWL-BIL	1478.87	93.81	490.46	215.12	679.48	9
Market	EWL-BR	1130.17	77	312	201.1	540.07	9
Market	EWL-DES	1265.81	47.4	497.76	192.35	528.3	8
Market	EWL-HOU	1089.44	61.7	436.88	195.42	395.44	5
Market	EWL-LC	2136.77	157.38	595.48	359.68	1024.23	14
Market	EWL-NO	1369.72	75.45	377.42	217.53	699.32	8
Man-made Canal	EWL-T-01A	1817.89	107.73	576.03	292.96	841.17	10
Man-made Canal	EWL-T-01	1198.12	71.93	352.63	251.67	521.89	7
Man-made Canal	EWL-T-02	4191.67	262.89	1288.99	651.18	1988.61	24
Man-made Canal	EWL-T-03	2353.06	146.04	682.22	498.48	1026.32	14
Man-made Canal	EWL-T-04	1410.84	79.16	410.36	267.35	653.97	7
Man-made Canal	EWL-T-05	1709.2	105.94	513.63	330.27	759.36	9
Man-made Canal	EWL-T-06	1321.49	76.35	390.12	250.91	604.11	8
Man-made Canal	EWL-T-07	1676.49	103.62	497.24	295.65	779.98	10
Man-made Canal	EWL-T-08	1855.62	101.3	589.73	337.59	827	9
Man-made Canal	EWL-T-09	1501.43	102.56	476.66	271.67	650.54	9
Man-made Canal	EWL-T-10	2414.99	158.72	714.98	421.94	1119.35	14
Man-made Canal	EWL-T-11	1088.14	71.13	344.33	197.52	475.16	6
Man-made Canal	EWL-T-12	1543.47	107.41	481.09	235.08	719.89	10
Schooner Bayou	EWL-TR-01	1250.18	78.71	370.59	185.72	615.16	8
Schooner Bayou	EWL-TR-02	1465.06	96.92	386.97	296.57	684.6	11
Schooner Bayou	EWL-TR-03A	1324.84	95.3	421.76	210.12	597.66	8
Schooner Bayou	EWL-TR-03	1516.65	98.16	429.18	306.53	682.78	11
Schooner Bayou	EWL-TR-04	1839	101.61	597.61	280.04	859.74	12
Schooner Bayou	EWL-TR-05	1386.91	103.08	425.39	215.03	643.41	6
White Lake	EWL-TR-06	961.39	70.32	327.25	146.36	417.46	5
White Lake	EWL-TR-07	1573.82	98.95	533.92	233.43	707.52	8
White Lake	EWL-TR-08	1242.83	103.14	402.52	176.81	560.36	7
White Lake	EWL-TR-09	1284.16	108.54	405.71	183.62	586.29	6

Study Area Water Chemistry

Salinity

The range of salinity was determined by the evaluation of electrical conductivity and temperature at each sample location to determine if the habitat within the three areas of investigation in the White Lake watershed were conducive for blue crab propagation and persistence. As discussed previously blue crab habitat salinity varies based on seasonality, life stage, and sex. The salinities in 22 of the 23 locations was ≤ 2.8 ppt with the highest salinity located at TR-05 of 4 ppt. Males prefer low salinity and the identification of sex from the 307 crabs caught indicated that 245 or 80% of the crabs were male. Perry and McIlwain (1986) determined that blue crabs inhabit waters with salinity less than 5.0. The salinity determined from the three areas of investigation provides suitable habitat for blue crab populations in both natural and man-made waterways and waterbodies.

Temperature

The role water temperature plays on the development and growth of blue crabs has conflicting results in scientific literature between field observations and laboratory tests. The crabs evaluated in this study were non-molting adults caught during the winter, so a comparison to water temperatures for juvenile development is not applicable. Tagartz (1968) observed blue crabs in water with temperatures ranging from 13.8 C to 32.1 C. Perry and McIlwain (1986) determined that blue crabs are present in water with temperatures below 13.0 C and noted that development will cease until temperatures increase.

The study area has a positive correlation between the size of the water body and the measured temperature, with White Lake having the lowest temperatures, with higher temperatures in Schooner Bayou, and the highest temperatures in the man-made canals. Blue

crabs were caught at all locations independent of temperature indicating that blue crabs are tolerant of temperatures between 8.47 C and 13.84 C during the winter in the White Lake watershed.

Dissolved Oxygen

The EPA defines levels of normoxia for dissolved oxygen that do not adversely affect crustaceans at 8 ppm. The mean concentration of dissolved oxygen measured from the 23 sampling locations within the White Lake watershed is 9.82 ppm. All dissolved oxygen measurements were greater than the 2.5 ppm concentration that the EPA defines as hypoxic and deleterious to crustacean health under chronic exposure. Therefore, the measured dissolved oxygen concentration in the study area is acceptable for blue crab habitat.

pH

The habitat requirements of blue crabs for pH are similar to that of temperature in that the scientific literature has conflicting evidence between laboratory and field studies. Laughlin et al. demonstrated in laboratory assessments that blue crab avoidance occurred in acidic water with pH ranging from 4.6 to 5.8, but observed an abundance of smaller crabs in the field inhabiting acidic waters below pH of 4.6. The pH measurements acquired from the 23 sample locations within the watershed all fall within the normal range (6.5 and 9.0) for freshwater as defined by EPA Aquatic Life Criteria developed under Section 304(a) of the Clean Water Act between. The pH of natural and man-made waterways and waterbodies in the White Lake watershed ranged between 6.76 and 7.72 during the study which supported blue crab habitat.

Study Area	Site ID	Date	Time	Water Sample Depth [ft]	Temp [C]	p H [pH]	Cond [µS/cm]	Turb [NTU]	DO [mg/L]	ORP [mV]
Man-made Canals	T-01A	12/15/2010	1237	2.200	11.33	7.09	2871	367.0	9.24	0.16
	T-01	12/20/2010	1236	1.000	12.15	7.40	3930	51.3	7.48	0.05
	T-02	12/20/2010	1228	1.100	12.58	7.50	3946	48.1	8.37	0.11
	T-02	12/21/2010	1104	1.100	13.84	7.40	4019	45.2	8.05	0.01
	T-03	12/16/2010	1238	2.000	13.81	7.41	3154	70.1	9.45	0.09
	T-04	12/16/2010	1237	1.200	13.61	7.47	3120	110.0	9.27	0.13
	T-04	12/20/2010	1222	1.000	12.35	7.45	3965	45.9	8.05	0.14
	T-05	12/20/2010	1208	1.100	12.11	7.46	3170	46.4	9.48	0.12
	T-05	12/21/2010	1033	1.300	13.40	7.26	3512	46.5	8.95	0.07
	T-06	12/16/2010	1215	1.000	13.79	7.25	3145	65.6	9.32	0.26
	T-06	12/20/2010	1204	1.170	12.57	7.48	3185	48.2	9.83	0.13
	T-07	12/21/2010	1018	1.100	12.97	6.91	2856	88.1	9.12	0.22
	T-08	12/20/2010	1147	1.500	11.81	7.53	2768	95.2	9.72	0.15
	T-09	12/16/2010	1143	1.500	12.73	6.82	2673	233.0	12.29	0.2
	T-10	12/20/2010	1157	1.300	12.34	7.44	3200	48.5	9.30	0.18
	T-11	12/21/2010	1053	1.300	13.49	7.41	3358	59.0	8.64	0.02
	T-12	12/20/2010	1128	0.890	11.77	7.72	2755	92.3	9.29	0.18
Schooner Bayou	TR-01	12/15/2010	1126	1.400	9.84	6.76	2523	52.0	11.56	0.21
	TR-02	12/20/2010	1120	1.900	10.74	7.02	5239	18.2	7.25	0.19
	TR-03A	12/14/2010	1507	1.000	8.84	7.49	2303	134.0	11.03	0.19
	TR-03	12/20/2010	1107	1.000	11.66	6.99	2944	52.1	11.72	0.22
	TR-04	12/14/2010	1450	1.400	9.89	7.45	2361	154.0	10.97	0.19
	TR-05	12/14/2010	1440	0.833	8.81	7.50	2263	137.0	11.30	0.22
White Lake	TR-06	12/14/2010	1347	0.910	8.60	7.40	2267	110.0	11.21	0.24
	TR-07	12/14/2010	1350	1.170	8.56	7.44	2249	177.5	11.42	0.21
	TR-08	12/14/2010	1425	1.600	8.75	7.44	2243	165.0	11.42	0.24
	TR-09	12/14/2010	1400	0.500	8.47	7.44	2198	179.0	11.35	0.18

Table 8: Water Chemistry. Readings obtained using the In-Situ Troll 9500. Daily calibration conducted using In-Situ Inc, Quik Cal Solution.

Human Health Risk Assessment

Barium

The LDHH recognizes barium as a noncarcinogen. In this study, LDHH measured barium concentrations in crab tissue and fat to determine if the concentrations yielded a dose of barium when consumed that is protective of human health. LDHH used EPA's chronic exposure Reference Dose (RfD) for barium of 0.2 mg/kg-day (ATSDR, 2007b) as is the protective health goal. The RfD is a lifetime exposure risk to human population designated by duration and route of exposure (LDHH, 2011). The RfD is an estimate of exposure that is likely to be without appreciable risk of adverse health effects over a lifetime. The assumptions used by the LDHH for the estimate of exposure to barium through the consumption of blue crabs from the White Lake watershed are presented below.

Assumption	Variable	Unit
Body Weight	70	kg
Meal Amount	0.227	kg/meal
Exposure Time	30 and 70	Year
Averaging Time	70	Year
Meal Frequency	52 (or 1)	Meals per year (or meals per week)

Table 9: Assumptions used to derive barium dose (mg/kg-day) to compare to EPA Chronic RfD

The calculated dose of barium, as estimated by the LDHH, from blue crabs from the White Lake watershed consumed by humans for one meal per week for 30 years and for 70 years is estimated to be below the EPA's chronic exposure reference dose of 0.2 mg/kg-day. Therefore, the estimate is that there are no predicted adverse health effects from consumption of the crabs.

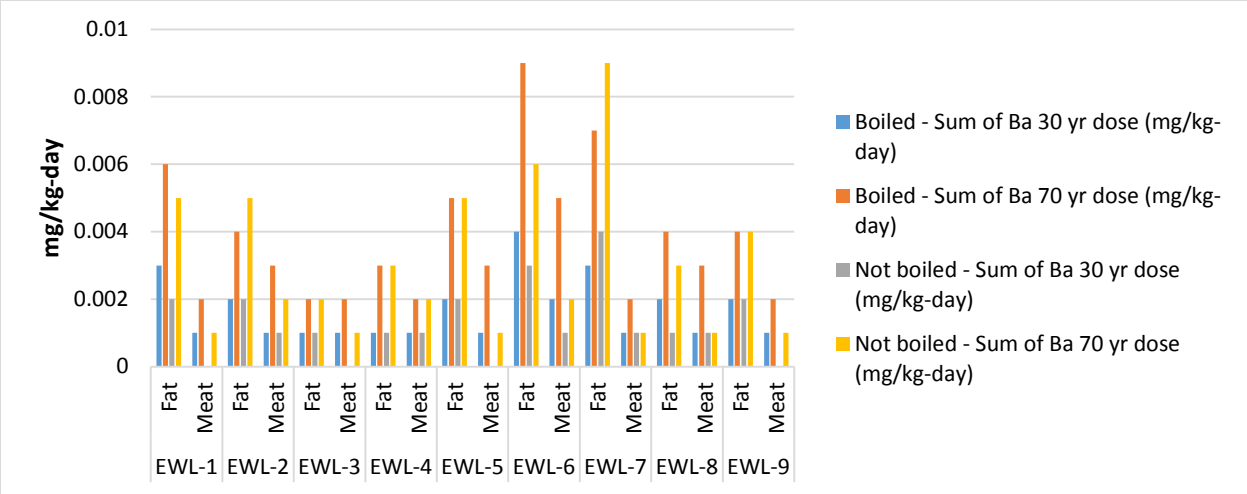

Figure 18: Assumed dose of barium from consumption of boiled and not boiled crab fat and meat

Arsenic

The LDHH recognizes arsenic as a carcinogen. In this assessment of risk to human health, the meat and fat tissues were analyzed for total arsenic with and without boiling. The Louisiana Tissue Screening Level (TSL) was used as the standard for comparison for comparing the concentration of arsenic in crab fat and tissue. The TSL is based on the oral slope factor for inorganic arsenic of 1.5 per mg/kg-day. The TSL is 0.36 mg/kg for arsenic in crab tissues, based on the estimated consumption of combined crab tissue and fat (LDHH, 2011). Meat tissue in both boiled and not boiled category were all non-detect (0.50 mg/kg) for total arsenic. A total of 11 samples out of the 36 were detectable for arsenic and exceeded the LA TSL for arsenic. The 11 samples were from crab fat in both the boiled and not boiled category. Because LDHH uses the assumption that only 1.5% of a given meal will be crab fat, when fat plus tissue is assumed to be ingested, the total TSL is below 0.36 mg/kg for total crab fat and tissue. It is also important to note that the samples are assumed to be inorganic arsenic. Crabs and seafood contain concentrations of organoarsenic compounds that are

nontoxic and this is not accounted for in the assessment, as the assumption is that the arsenic is 100% inorganic.

Site	Tissue/Preparation	As (mg/kg)		Site	Tissue/Preparation	As (mg/kg)
EWL-6	Fat/Not Boiled	0.816		EWL-7	Fat/Not Boiled	0.606
EWL-3	Fat/Not Boiled	0.770		EWL-2	Fat/Boiled	0.593
EWL-4	Fat/Not Boiled	0.749		EWL-7	Fat/Boiled	0.565
EWL-6	Fat/Boiled	0.720		EWL-9	Fat/Not Boiled	0.544
EWL-2	Fat/Not Boiled	0.672		EWL-4	Fat/Boiled	0.512
EWL-1	Fat/Boiled	0.634				

Table 10: Analytical results from LDHH study for total arsenic

Seafood is a major source of arsenic in the human diet, however it is primarily in the organic, less toxic form and is generally not considered a threat to human health (LDHH, 2011). There were no detectable concentrations of total arsenic in the meat tissue and arsenic was only found in the hepatopancreas or fat. The U. S. Food and Drug Administration conducts the Total Diet Study which purchases consumer foods and tests them for a list of analytes, including arsenic. For comparison, the median arsenic concentration from samples analyzed for the Total Diet Study includes: tuna canned in oil (0.91 mg/kg), frozen fish sticks (0.674 mg/kg), tuna (0.921 mg/kg), haddock (5.64 mg/kg), and shrimp (0.514 mg/kg). All sample results for total arsenic of tissue and hepatopancreas in blue crabs from the White Lake watershed fall within the normal range for seafood samples analyzed by the FDA as part of the Total Diet Study.

Site ID	Sample Description	Preparation	Ba Result (mg/kg)	Ba 70 yr dose (mg/kg-day)	Ba 30 yr dose (mg/kg-day)	As Result (mg/kg)
EWL-1	Fat	Not boiled	9.86	0.005	0.002	<0.50
EWL-2	Fat	Not boiled	10.4	0.005	0.002	0.672
EWL-3	Fat	Not boiled	4.98	0.002	0.001	0.770
EWL-4	Fat	Not boiled	6.19	0.003	0.001	0.749
EWL-5	Fat	Not boiled	9.92	0.005	0.002	<0.50
EWL-6	Fat	Not boiled	13.8	0.006	0.003	0.816
EWL-7	Fat	Not boiled	19.5	0.009	0.004	0.606
EWL-8	Fat	Not boiled	7.17	0.003	0.001	<0.50
EWL-9	Fat	Not boiled	9.39	0.004	0.002	0.544
EWL-1	Fat	Boiled	13.1	0.006	0.003	0.634
EWL-2	Fat	Boiled	8.36	0.004	0.002	0.593
EWL-3	Fat	Boiled	4.53	0.002	0.001	<0.50
EWL-4	Fat	Boiled	6.78	0.003	0.001	0.512
EWL-5	Fat	Boiled	11.9	0.005	0.002	<0.50
EWL-6	Fat	Boiled	20.2	0.009	0.004	0.720
EWL-7	Fat	Boiled	16.1	0.007	0.003	0.565
EWL-8	Fat	Boiled	8.38	0.004	0.002	<0.50
EWL-9	Fat	Boiled	8.79	0.004	0.002	<0.50
EWL-1	Meat	Not boiled	1.89	0.001	0.000	<0.50
EWL-2	Meat	Not boiled	3.28	0.002	0.001	<0.50
EWL-3	Meat	Not boiled	2.29	0.001	0.000	<0.50
EWL-4	Meat	Not boiled	3.85	0.002	0.001	<0.50
EWL-5	Meat	Not boiled	2.19	0.001	0.000	<0.50
EWL-6	Meat	Not boiled	4.95	0.002	0.001	<0.50
EWL-7	Meat	Not boiled	2.92	0.001	0.001	<0.50
EWL-8	Meat	Not boiled	2.93	0.001	0.001	<0.50
EWL-9	Meat	Not boiled	1.24	0.001	0.000	<0.50
EWL-1	Meat	Boiled	3.86	0.002	0.001	<0.50
EWL-2	Meat	Boiled	5.55	0.003	0.001	<0.50
EWL-3	Meat	Boiled	4.88	0.002	0.001	<0.50
EWL-4	Meat	Boiled	4.77	0.002	0.001	<0.50
EWL-5	Meat	Boiled	5.85	0.003	0.001	<0.50
EWL-6	Meat	Boiled	11.2	0.005	0.002	<0.50
EWL-7	Meat	Boiled	4.71	0.002	0.001	<0.50
EWL-8	Meat	Boiled	5.45	0.003	0.001	<0.50
EWL-9	Meat	Boiled	3.39	0.002	0.001	<0.50

Table 11: Total barium and total arsenic analytical data and barium reference dose (30-yr and 70-yr) calculations from the LDHH study

CHAPTER 4

CONCLUSIONS

The purpose of this study was to assess the population of blue crabs within a mix of natural and man-made habitats in the White Lake watershed and present a human health risk assessment for concentrations of total arsenic and barium. The collection effort included identifying potential blue crab habitat, recording field measurements of water quality, baiting and setting crab traps and hoop nets, collecting and identifying specimens, completing a field record for each location, packing and shipping crabs for analytical testing. The results of the collection effort demonstrate that the population of blue crabs in the White Lake watershed are healthy and robust.

Healthy and Robust Blue Crab Population

Three areas of investigation (White Lake, Schooner Bayou, man-made canals) were selected to determine the blue crab habitat in the White Lake watershed. Blue crabs were caught in traps from all three waterbodies, indicating that the ecosystem supports all physical, chemical, and biological conditions for them to live and reproduce. A comparison of the fullness of the crabs between the three areas of investigation demonstrate that the population is uniform in size and weight with crabs measuring 20 cm in width being caught in each area. The average "fullness" calculated for the three habitats: White Lake (1.9 g/cm^2) , man-made canals (1.9 g/cm^2), and Schooner Bayou (1.8 g/cm^2) The average carapace width from the man-made canals, Schooner Bayou, and White Lake ranged between 15.4 cm and 17 cm, 15.1 cm and 18 cm, and 16.2 cm to 17.5 cm respectively. These sizes are consistent with regulatory size and average size of harvestable crabs along the Gulf Coast.

One source of uncertainty in the study collection effort comes from the ease with which crabs were caught in White Lake as compared to the other study areas. Another area for

further investigation is that the water temperature and salinity at the four locations in White Lake were generally lower than in Schooner Bayou and the man-made canals. Other investigation would be a seasonal study to help determine if the placement of the crab traps at the mouth of White Lake would increase the catch by being located along a migratory route.

Market Crab Comparison

In addition to conducting an inter-watershed analysis from White Lake, market crabs from the Gulf Coast were purchased for comparison of tissue weight. Using the Wilcoxon's test statistic it was determined that the average tissue weight of White Lake watershed crabs were not significantly different than the six markets evaluated. It is valuable to note that the blue crabs purchased from the market were generally "select" crabs, meaning that on average they were determined by the markets to be the larger individuals for sale. The average total tissue weight from the White Lake watershed (178.35 g) is greater than the average total tissue weight of 5 of the 6 markets. The average total tissue weight provides evidence that the White Lake watershed produces blue crabs of expected size and weight compared to markets along the Gulf Coast.

Further areas of investigation could include a greater number of individual crabs purchased at each market which would include "select" and "normal" size. Additionally, market crabs from Lafayette that come from White Lake could also be evaluated (assuming they are also "select" size) to account for the crabs below LDWF regulatory size limit that were included in the study.

An additional study of market crabs would be valuable. The range of habitats for the market crabs could be the determining factor for tissue weight. Water chemistry and physical structure of the blue crab habitat for market sources would assist in determining if low water temperature and salinity are contributing factors to presence of a large crab population.

Water Chemistry

The water chemistry measured at sampling locations within the man-made canals, Schooner Bayou, and White Lake identifies water that supports blue crabs in abundance. Blue crabs are mobile and migrate great distances throughout their lifetime and have been observed leaving or avoiding habitats with poor water quality. Adult male blue crabs prefer waterbodies with low salinity, which is present at White Lake and supports a typical, healthy and robust population of blue crabs. Eighty percent of individuals caught during the study were male, as was expected with water salinities ≤ 2.8 ppt. Additional parameters, including pH, temperature, and DO all fall within the expected ranges for appropriate blue crab habitat.

The LDWF in a collaborated effort with the National Oceanic and Atmospheric Administration conducted dockside surveys in Louisiana of commercial crab fisherman and calculated the CPUE from 2000-2013. The average CPUE for Louisiana was 1.34 pounds with the Mississippi River basin (3.25 pounds/ trap day) being the greatest and lowest being in the Vermilion/Teche River basin (1.15 pounds/ trap day) (Bourgeois et al., 2014). The Total CPUE for the three habitats are all greater than the Louisiana average and 2 to 5 times greater than the Vermilion/Teche River basin in which the site is located. The range of Totoal CPUE is from 2.49 pounds/ trap day to 6.19 pounds/ trap day with an average of 4.32 pounds/trap day. White Lake has the highest average CPUE of 4.78 pounds/trap day of the three habitats followed by the man-made canals and Schooner Bayou at 4.63 and 3.92 pounds/ trap day, respectively. The CPUE demonstrates that the water chemistry in the mixed natural and man-made habitats in the White Lake watershed support blue crab population in abundance.

Human Health Risk Assessment

The Human Health Risk Assessment conducted by the LDHH determined that blue crabs are safe to consume and there is no expected risk from total barium and total arsenic from crab meat tissue and fat regardless of whether the crab is boiled or raw. Barium is a noncarcinogen and all levels were below the EPA's chronic exposure reference dose of 0.2 mg/kg-day. for chronic exposure for 30 and 70 years.

Arsenic was determined to be at levels protective of human health in both the meat tissue and "fat'. The analysis of meat tissue in both boiled and not boiled category were all non-detect (0.50 mg/kg) for total arsenic and the LDHH concluded that only 1.5% of a given meal will be crab fat, when fat plus tissue is assumed to be ingested, and the total TSL is below 0.36 mg/kg for total crab fat and tissue.

Another area of study would be the speciation of arsenic in blue crab tissues to determine the concentrations of inorganic and organic arsenic. The speciation may also provide essential information in determining why arsenic levels were not detected in the meat tissue and only in the fat

The study found a robust and healthy blue crab population in a mixed natural and man-made habitat within the White Lake watershed of Vermilion Parish, Louisiana. Crabs were determined to be the expected width, length, and weight when compared to individuals purchased from markets across the Gulf Coast. A human health risk assessment concluded that the detected limits of total arsenic and total barium are expected to be safe for human consumption.

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BIOGRAPHICAL SKETCH

Throughout my life I've enjoyed spending time outside in various ecosystems, including: camping in the longleaf pine savannas of Mississippi, trail running in the giant sequoia forests of northern California, hunting in the prairies of Kansas, snow skiing in the mountains of Colorado, water skiing in wetland bayous of Louisiana and fishing in the Gulf of Mexico.

I began to understand the fragile nature of ecosystems, the need for sustainable living and the vital role humans played in their preservation while living in Kansas. I was made aware of the fragility of fresh water available in the Ogallala Aquifer from the farmers and ranchers I met and worked with. I witnessed the deleterious effect of climate change and the long standing environmental policies of fire suppression within the forest service have had in the neighboring Colorado. As my understanding of the complex relationship between human interests and the environment grew, so did my desire to become integrated in the process.

My professional career began in the classroom. After graduation from Tulane University in Ecology and Evolutionary Biology, I was eager to teach others the importance of sustainable living and preservation of natural resources and the environment. I taught Environmental Science at the high school level. An integral part of the class included a daily science topic and news article. We would discuss the topic and review the importance and relevance it had on our daily lives. I learned a great deal from my teaching experience and from my students. I felt that my instruction came from second hand experience and that I would become more effective if I had lived what I was teaching. One of my life goals is to return to the classroom following years of first-hand experience collaborating with environmental professionals regarding environmental issues and working in cooperation with industry and environmental policy.

The decision to leave teaching was difficult, but in a post Hurricane Katrina New Orleans, I felt more than ever the importance of understanding the role of the ecological systems in south

Louisiana. The loss of wetlands and failure to create working engineering controls had a direct impact on the severity of the storm. I began working on a Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA-1990) funded project called the Coastwide Reference Monitoring System-Wetlands (CRMS). CRMS' purpose is monitoring the effectiveness of individual wetland restoration projects as well as monitoring the cumulative effects of all projects in restoring, creating, enhancing, and protecting the coastal landscape of Louisiana. During my work on CRMS I was responsible for piloting an assortment of boats and airboats to monitoring sites located throughout the Atchafalaya, Barataria, and Terrebonne hydrologic basins. My tasks included collecting hydrology, herbaceous marsh vegetation, forested swamp vegetation, soil properties, soil accretion, and surface elevation data. The experience gave me a strong base knowledge of environmental sampling techniques, instrumentation, and data management.

Following my work on the CRMS project, I began working with Michael Pisani and Associates, Inc. (MP&A), an environmental consulting company that works with land owners and industry on many projects including oil and gas field litigation support, site investigation*, Resource Conservation and Recovery Act (*RCRA)*, Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA), and remediation projects regulated by both state and federal agencies. MP&A is a small corporation with less than 20 employees, which has proven beneficial to my professional development. I have worked on over 50 projects with a varying degree of involvement including: site investigations; historical research; surface water, groundwater, sediment, soil, and fauna sampling; rapid bioassessment of periphyton, macroinvertebrates and fish, wetland delineation; aquifer testing; elevation surveying; Naturally Occurring Radioactive Material (NORM) surveying and sampling.

The advantage of working for a small company that has an experienced environmental engineer as the owner is that it allows each individual within the company the opportunity to become well rounded in all aspects of field work, data compilation and interpretation, state and federal

agency regulation and compliance, client interaction, project management, and report drafting. This atmosphere has provided the pathway to become what I feel as a vital element in working towards environmental sustainability and preservation. It has also allowed me to pursue continuing education from the University of Florida.

All of this has been made possible with the loving support of my wife Jessica and sons, Liam and Jameson.