COMPARISON OF ENDOHELMINTH PARASITES IN BLACK DRUM (*POGONIAS CROMIS*) AND RED DRUM (*SCIAENOPS OCELLATUS*) FROM THE SABINE LAKE ESTUARY

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by

Hannah C. McNeese

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DEDICATION

This thesis is dedicated to my father and my brother, who are no longer present to see its completion. The loss of the two most important men in my life has affected me greatly, but they would not stand for me to give up. They have been a constant source of motivation for the completion of this thesis, and of my master's program. I know that both would be proud to see the project completed, even if they could not understand my fascination with parasites.

ABSTRACT

McNeese, Hannah C., *Comparison of endohelminth parasites in black drum (Pogonias cromis) and red drum (Sciaenops ocellatus) from the Sabine Lake estuary.* Master of Science (Biology), May, 2021, Sam Houston State University, Huntsville, Texas.

The black drum (*Pogonias cromis*) and the red drum (*Sciaenops ocellatus*) are two closely related fish species that occur throughout the Gulf of Mexico. These species utilize estuarine systems as brooding grounds for their young, which offers some protection, and readily available food sources to the juvenile individuals. This study sought to understand how endo-parasitic communities of juvenile and sub-adult individuals of these two drum species compared, and sought to determine what the effects of host size and habitat salinity were on the parasitic communities in each fish species and between fish species. We conducted a helminth survey on black drum (n=59) and red drum (n=61) that were caught from Sabine Lake in the spring and summer of 2018. The overall parasitic intensity and the Shannon-Wiener diversity were calculated for each individual fish, and were compared to host size and habitat salinity, respectively, via linear regression to determine effects of the factors on the parasite community. Parasitic communities were compared between fish using Jaccard's index, Hutcheson-t test of Shannon-Wiener diversity, Percent Similarity index, and a mixed-effects model. Percent similarity index and the mixed effects model were used to determine if host size and habitat salinity affected the similarity of the parasitic communities to one another. From these fish we have identified 38 parasite species (23 nematodes, 6 trematodes, 5 acanthocephalans, and 4 cestodes). The relationship of host size and intensity of parasitic infections was found to be significant for both the black (R^2=0.29, $p<0.05$) and the red drum(R^2=0.16, $p<0.05$). The Jaccard index value was 0.2895, or 28.95% similarity

between the communities, and Hutcheson-t did show significant difference ($p<0.05$) in diversity between the two communities. The highest percent similarities were between the small sized black and red drum, and between the black and red drum caught in the lowest salinities. This study is significant as a primary helminth survey from Sabine Lake, and as new host and locality documentations for several parasite species.

KEY WORDS: Red drum; Black drum; Endohelminths; Sabine Lake; Texas; Parasites; Parasitic communities

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CHAPTER I

Introduction

Parasitism

Parasites are organisms that are required to inhabit another organism for surviving and reproducing (Loker and Hofkin 2015). Parasites can be either internal or external to their host and can have complex life cycles. Some parasites use only one host for their entire life cycle, while others require several different intermediate hosts to complete the development of different life stages (Loker and Hofkin 2015). Intermediate hosts are organisms in which parasites will live and grow, but sexual reproduction occurs in the definitive host, which is the "final" phase in the parasite life cycle and is most often a different organism than the intermediate host (Loker and Hofkin 2015). External parasites are usually acquired through interaction with the environment, or through active movement of the parasite onto the host body (Loker and Hofkin 2015). Internal parasites are primarily acquired via ingestion of eggs from the environment, ingestion of free-living larvae stages, ingestion of intermediate host organisms, or by larvae burrowing through the outside of an organism (Loker and Hofkin 2015).

The two species of drum surveyed in this study serve as both an intermediate and definitive host for many species and may often contain both larval and adult parasites (Alarcos and Etchegoin 2010; Matlock 1990). It is not uncommon for a host organism to act as an intermediate host for some parasites and a definitive host for other parasites at the same time, but most parasites will not have multiple life stages in one host (Loker and Hofkin 2015). Within intermediate hosts, parasites are often encysted within muscle tissues, mesenteries, or even inside organs such as the liver. Encysted parasites can be at

varying stages of development but will not be reproductively active (Loker and Hofkin 2015). Definitive hosts are infected with reproductively active (adult) parasites typically equipped with some form of attachment organ to maintain their position within their preferred host microhabitat (Loker and Hofkin 2015).

Many factors are thought to influence the selected habitat and survival of a parasite with a host. Factors like pH, oxygen concentration, nutrient availability, host immune response, likelihood of ingestion by the next host, and interactions between parasites are all likely to influence habitat selection and survival for any given parasite (Loker and Hofkin 2015). This study primarily examines intestinal and mesenteric habitats, as well as the stomach, liver, and spleen when available. The mesenteries, liver, and spleen should all have a consistent pH, oxygen concentration, and nutrient availability in the host body as they are fed by the blood stream. However, the intestines and stomach might not experience the same consistency. The production of digestion enzymes fluctuates through time, which would be reflected in pH and nutrient availability fluctuations throughout the day. Additionally, hosts may consume portions of the environment along with their food items, which could affect factors such as oxygen availability.

The above factors are those that are understood, but little information exists about how salinity might affect parasite habitat selection and survival in a host. Salinity would not be a consideration for organisms outside of the aquatic environment in most cases, but salinity tolerance is significant for all organisms in water. Organisms that travel between differing salinities are known to have adaptations to deal with osmoregulation, and organs like the mesenteries, liver, and spleen would not be affected from one salinity

to another. However, in the context of the stomach and intestines, contact with water from different salinities is unavoidable as the host swallows at least some water any time it consumes a food-item. This inevitable interaction begs the question of whether or not parasites can deal with the issues as their hosts do, or does the host shifting salinities cause parasites to perish.

Host Organism Life Histories

The black drum (*Pogonias cromis*) and the red drum (*Sciaenops ocellatus*) are closely related fish species in the family Sciaenidae, also known as the drums or croakers (Cheng et al. 2012, Sasaki 1989). Adults of both species live in the open waters of the Gulf of Mexico, but spawn in nearshore waters of the gulf, which allows their larvae, juveniles, and sub-adults to utilize estuaries as nursery grounds (Matlock 1990; Peters and McMichael 1990). These fishes reach sexual maturity (adulthood) at different sizes and the maturation process takes different amounts of time. Murphy and Taylor (1989) found that black drums typically became adults at 675 mm (around 6 years old for males) and between 650 and 699 mm (5 or 6 years old for females). Red drum mature earlier (about 3 to 4 years old), and at larger sizes (750 mm or greater) (Matlock 1990). The growth rate of red drum is much faster than that of the black drum. Red drum grow at a rate of 18.8 mm to 32.4 mm per month, whereas black drum average about 10 mm per month, and most black drum only reach a maximum of 100 mm in length after a year of growth (Bass and Avault 1975; Murphy and Taylor 1989; Overstreet 1983).

Black Drum Life History

Juvenile black drums most often occur in moderate and low salinity habitats and seem to prefer areas that have muddy substrate with little to no vegetation (Peters and

McMichael 1990). Individuals smaller than 60 mm tend to feed on copepods, polychaetes, and siphon tips of bivalves, while individuals larger than 60 mm tend to prey on whole bivalves, gastropods, and rarely other fish (Peters and McMichael 1990). This disparity and change in diet has to do with the formation of chin barbels and pharyngeal teeth (Peters and McMichael 1990). The pharyngeal teeth and musculature controlling the pharyngeal jaws of young fishes are not as well developed as those of their adult counterparts, leading them to feed on smaller shelled, or shell-less prey-items until these structures develop fully (Grubich 2000). Peters and McMichael (1990) noted that fish diet varied based on the location of fish collection. The fact that diet varied by location can be linked to salinity variability, as the fish were collected from areas that were of high, moderate, or low salinity (Peters and McMichael 1990). Black drum adults prey on mollusks and decapod crustaceans and have specialized pharyngeal crushing teeth and pharyngeal jaw musculature, which they can use to crush the hard, external shells of bivalves, such as oysters (Grubich 2000). The ontogenetic shifts in diet for the black drum are smaller and less apparent than they are for the red drum, as the black drum begin their molluscivory at a small size, and thus a younger age.

Red Drum Life History

Red drum juveniles primarily occur along shorelines and in sea grass meadows as habitats (Matlock 1990). Sea grasses grow more readily in saltier habitats meaning there could potentially be a preference by red drum juveniles for higher salinity waters, although this was not explicitly stated by Matlock (1990). Juvenile red drum diet is comprised of five main taxa: Copepoda, Amphipoda, Mysida, Decapoda, and all manner of teleost fishes (Bass and Avault 1975). The smallest of juveniles prey upon copepods,

amphipods, and mysid shrimps. However, when the fish reaches a size of about 70 mm, the diet becomes more focused on decapod prey items like the blue crab (*Callinectes sapidus*) (Bass and Avault 1975). Other fishes become most important in the diet when the juveniles are around 120 mm length and remain an important food source thereafter (Bass and Avault 1975). In adulthood, the diet becomes primarily fish based, though the red drum will opportunistically eat anything soft-bodied and are known to eat shrimp with some frequency (Grubich 2000; Matlock 1990).

The black drum and red drum are species that are closely related enough that they are capable of hybridization, (Moore 2016; Henderson-Arzapalo et al. 1994). Some of these hybrids have been released into the wild, and there are unconfirmed reports of hybrids in the Gulf of Mexico (Moore 2016). This potential for natural hybridization, and the fact that these hybrids are grown for aquaculture in some cases (Henderson-Arzapalo et al. 1994), gives some credence to the need for comparative studies of the parasites of both fish species. Parasites require certain environmental conditions to be present in the host, and when those conditions aren't met, the parasite either cannot survive at all, or cannot reproduce (Loker and Hofkin 2015). The host may also have specific immune responses to parasitism that can potentially prevent some parasites from establishing and reproducing in the host (Loker and Hofkin 2015). A hybrid most likely exists somewhere in between its parent organisms in terms of immunological responses and physiology. Therefore, an understanding of the parent's parasites will give a good idea of what might infect a hybrid; the overlapped species of parasites between the two parent species are almost certainly capable of infecting the hybrid.

Current Knowledge of Drum Parasites

Current knowledge of the parasite communities of the black drum and the red drum are primarily based on adult individuals. As previously stated, there is a clear ontogenetic dietary shift for the red drum, and a minor dietary shift in the black drum. These shifts could lead to changes in the parasite communities of these fishes that previously have not been documented. Younger fishes should have parasites that they have acquired from their prey items and will not yet have acquired the parasites of their adult counterparts because they do not eat the same things. When a drum ingests a copepod, it will ingest a specific set of parasites, which may differ from the set of parasites it would gain from an oyster. The parasite community of each individual drum should shift based on what kinds of intermediate hosts it has ingested. Each type of parasite will infect a different intermediate host, even if they have the same definitive host. This means that diet is a crucial factor in determining the parasite species that infect a specific fish. Parasites also require specific conditions to survive within each host, and the precise temperature, pH, and salinity conditions can determine whether a parasite can survive within its host (Loker and Hofkin 2015).

In the Gulf of Mexico, there are 67 known species of parasites in black and red drum (Appendix). These parasites can be found throughout the fishes' bodies. However, this study focuses on intestinal helminths of black and red drum. In the intestines of these fish species there are 24 total parasites, which includes 9 nematodes, 3 cestodes, 1 myxozoan, 1 acanthocepalan, and 10 trematodes (Table 1). Apart from the three species of larval *Contracaecum* and the larval acanthocephalan species *Southwellina hispida*, these parasites are adults (Chandler 1935; Matlock 1990; Overstreet 1983). It is notable that

most of the parasites, 19 out of 24, were found in red drum (*S. ocellatus*)(Table 1). In contrast, only 4 of the species were found exclusively from black drum (*P. cromis*), and a single species, *Diplomonorchis leiostomi*, has been found in both fish species (Table 1). This skew in parasite finds may indicate that black drum parasites are not as widely studied in the Gulf of Mexico.

Table 1. *Intestinal and Mesenteric Parasites of Black and Red Drum Reported from the Gulf of Mexico*

Parasite Name	Host Species	Location in host	Geographic Distribution	Source(s)
Nematoda				
Contracaecum collieri	*Sciaenops ocellatus*	Body Cavity	Texas	Chandler, 1935
Contracaecum multipapillatum	*Sciaenops ocellatus*	Mesentery	Mississippi	Overstreet, 1983
Contracaecum sp.	*Sciaenops ocellatus*	Mesentery	Florida	Matlock, 1990
Dichelyne fastigatus	*Sciaenops ocellatus*	Intestine	Texas	Chandler, 1935; Matlock, 1990; Moravec et al, 2011
Dichelyne sp.	*Sciaenops ocellatus*	Intestine	Mississippi	Overstreet, 1983
Goezia kliksi	*Pogonias cromis*	Stomach	Louisiana	Deardorff and Overstreet, 1980
Goezia pelagia	*Sciaenops ocellatus*	Intestine	Mississippi	Overstreet, 1983
Hysterothylacium reliquens	*Sciaenops ocellatus*	Stomach and Intestine	Northern GMex and Mississippi	Overstreet, 1983
Spirocamallanus circotus	*Sciaenops ocellatus*	Intestine	Mississippi	Overstreet, 1983
Cestoda				
Poecilancistrium robust(um/us)	*Sciaenops ocellatus*	Intestine	Mississippi, Texas, and Florida	Matlock, 1990; Overstreet, 1983
Rhinebothrium sp.	*Sciaenops ocellatus*	Intestine	Mississippi and Florida	Overstreet, 1983
Scolex sp.	*Sciaenops ocellatus*	Intestine, Pyloric ceca	Mississippi	Overstreet, 1983
Myxozoa				
Henneguya ocellata	*Sciaenops ocellatus*	Intestinal and Cecal Epithelium	Florida	Matlock, 1990; Overstreet, 1983

(continued)

Parasite Name	Host Species	Location in host	Geographic Distribution	Source(s)
Acanthocephala				
Southwellina hispida	*Sciaenops ocellatus*	Mesentery	Mississippi	Overstreet, 1983
Trematoda (Digenea)				
Bucephaloides megacirrus	*Sciaenops ocellatus*	Intestine, Pyloric ceca	Texas, Florida, Louisiana, Mississippi	Overstreet, 1983; Simick and Underwood, 1996
Cotylogaster basiri	*Pogonias cromis*	Intestine	Texas, Louisiana, Mississippi	Simpson and McGraw, 1979
Cotylogaster dinosoides	*Pogonias cromis*	Intestine	Texas, Mississippi, Mexico	Simpson and McGraw, 1979
Diplomonorchis leiostomi	*P. cromis and S. ocellatus*	Intestine, Pyloric ceca	Texas, Louisiana, Mississippi, Florida	Simick and Underwood, 1996
Homalometron pallidum	*Pogonias cromis*	Intestine	Florida, Louisiana, Mexico	Curran et al., 2013
Lecithaster confusus	*Sciaenops ocellatus*	Intestine	Texas, Florida, Louisiana, Mississippi	Simick and Underwood, 1996
Lecithochirium mecosaccum	*Sciaenops ocellatus*	Stomach	Florida	Overstreet, 1983
Metadena spectanda	*Sciaenops ocellatus*	Intestine, Pyloric ceca	Texas, Louisiana, Mississippi	Overstreet, 1983
Opecoeloides fimbriatus	*Sciaenops ocellatus*	Intestine, Stomach, Pyloric ceca	Texas, Florida, Louisiana, Mississippi	Overstreet, 1983
Prosorhynchoides caecorum	*Sciaenops ocellatus*	Intestine, Pyloric ceca	Texas, Florida, Louisiana, Mississippi	Simick and Underwood, 1996

Note: Gulf of Mexico is abbreviated GMex. Geographic distribution refers to recorded locations for the parasite.

While no recent helminth surveys for black drum exist for the Gulf of Mexico, there are two relatively recent papers out of Mar Chiquita Lagoon, Argentina that survey black drum parasites (Alarcos et al. 2006; Alarcos and Etchegoin 2010). The parasites in these two studies are: *Dichelyne mariajuliae* (Nematoda), *Profilicollis chasmagnati* (Acanthocephalan), *Lobatostoma ringens* (Trematoda), *Microphallus szidati* (Trematoda), and *Neobrachiella chevreuxii* (Copepoda) (Alarcos et al. 2006; Alarcos and Etchegoin 2010). The Alarcos and Etchegoin paper is the first study of parasite community in black drums in Argentinian waters, and the discovery of *D. mariajuliae* (Alarcos et al. 2006) came from the same study being conducted for the Alarcos and Etchegoin paper. Alarcos and Etchegoin (2010) note in their paper that there are no

studies on the parasites of black drum in and around Argentina, aside from their own. This means the lack of knowledge for black drum parasites extends the length of their range and overlap of parasites could be possible between locations, it is simply unknown.

Purpose

This study surveys the intestinal and mesenteric parasite communities in black and red drum from the Sabine Lake ecosystem. No studies of parasite community have been conducted from this ecosystem, and no comprehensive studies of black drum parasites have been conducted in the Gulf of Mexico. I compared the parasite communities to host size and habitat salinity gradients to see if these factors contribute to parasite community structure. I predicted that parasite intensity would increase as host size increases (Figure 1A), because larger fish have eaten more prey-items than smaller fish in order to grow and will thus have collected more parasites from the larger amount of prey consumed. Larger fish will also have lived longer, which would allow them to have accumulated more parasites that burrow into the fish body over time. Habitat salinity is predicted to affect parasite diversity in a parabolic fashion (Figure 1b) as high and low salinity fish are predicted to have lower parasitic diversity than the moderate salinity fish. This study seeks to determine whether or not water salinity affects intestinal parasites, as fish are known to take gulps of water in with their food, which could kill off parasites that are not suited to water of a particular salinity. Low salinity tolerant parasites may be able to survive in moderately salty waters, but may not survive in high salinity water, and vice versa, so fish from moderate water would have the most diverse parasite community (Figure 1).

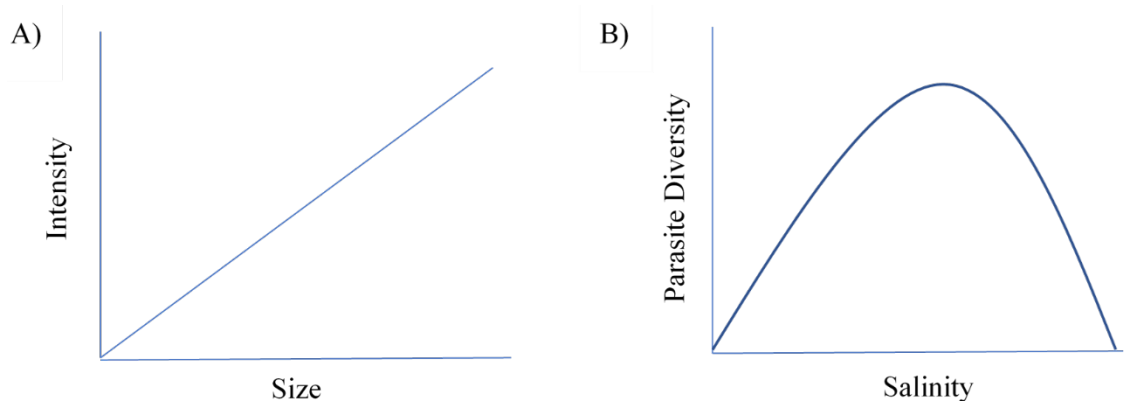

Figure 1. *Hypothetical Relationships of Size & Prevalence and Salinity & Diversity.* Note: Depicts the hypothesized relationships of A) host size and parasite intensity, and B) habitat salinity and parasitic diversity.

Additionally, the aim of this study is to compare black and red drum parasite communities, and determine if host size and habitat salinity affect the similarity of the parasite community. As these two fish species grow, they begin to inhabit more similar habitats, which could result in their parasite communities overlapping. This information could help us to understand how hybrid individuals of these two fish species will be parasitized, as it is becoming more likely that these fishes will hybridize with climate changes affecting the timing of breeding seasons (Moore 2016).

CHAPTER II

Materials and Methods

Study System

Fishes were collected from Sabine Lake, Texas, located in both Jefferson and Orange Counties. Sabine Lake is approximately 183.4 square kilometers and has a maximum natural depth of 3 meters (Tatum, 2009). This lake is an important fishery for both Texas and Louisiana, which are the two states that border the lake (Tatum 2009). The ecosystem is a brackish estuary, which makes it an ideal zone for many species to flourish. The lake starts at the mouth of the Sabine River and flows to the Gulf of Mexico via a channel that was constructed in 1972, and this channel was carved out to a depth of 12 meters (Tatum 2009). This relatively recent change means that there is a new diversification of species and habitats that were not present when the lake was solely a freshwater system (Tatum 2009). The mixing of fresh and salt waters may give rise to a mixing of parasite communities from the fresh and marine waters. There are currently no parasite studies from Sabine Lake, though several have been conducted within different areas of the Gulf of Mexico, as is mentioned in the previous chapter. Site numbers for this study correspond to the Texas Parks and Wildlife Department site designations for Sabine Lake (Figure 2).

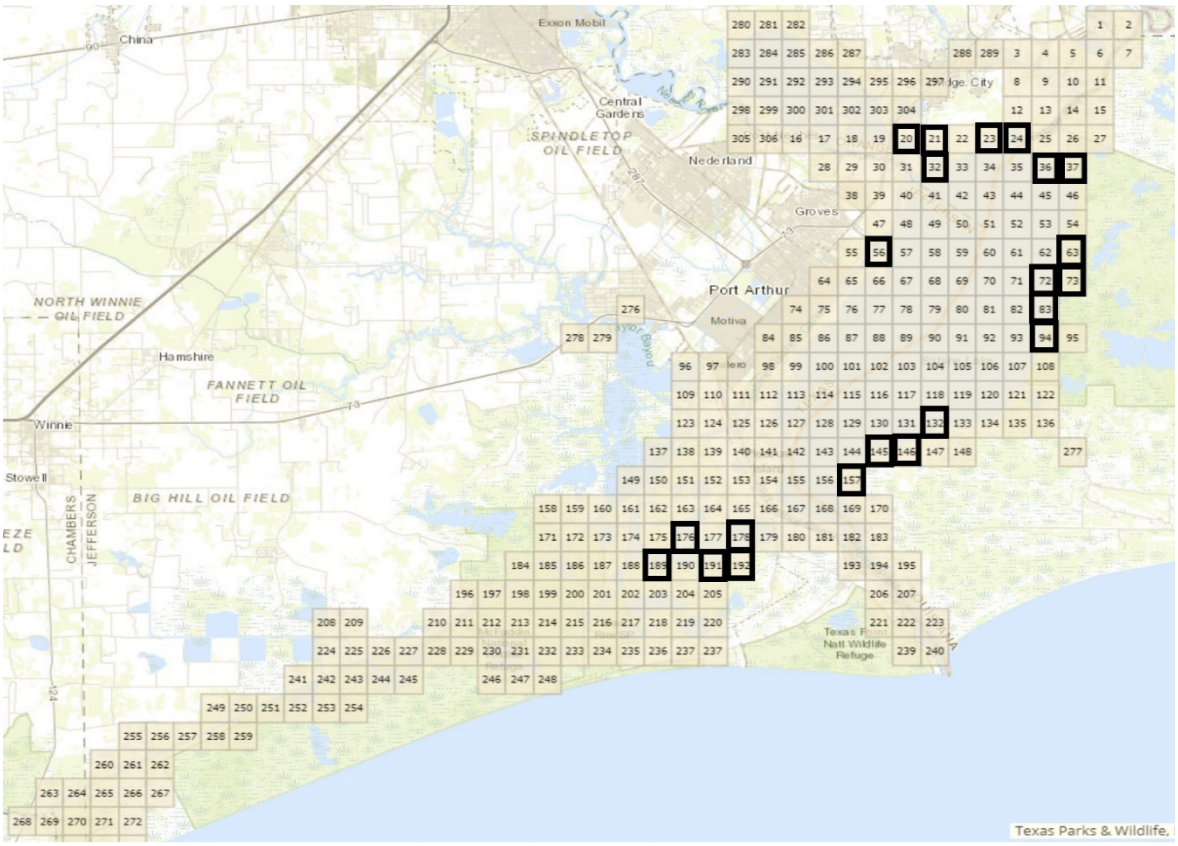

Figure 2. *Site Map of Sabine Lake.* Note: This map shows the sites in Sabine Lake as defined by the Texas Parks and Wildlife Department. These site numbers were recorded as part of the data set when the fish were collected. The sites outlined in a thick black box show the specific sites that the fishes in this study were caught in. (Texas Parks and Wildlife).

Fish Collection and Preparation

The fish necropsied in this study were collected by Dr. Phil Matich in conjunction with the Texas Parks and Wildlife department during the spring and summer of 2018 for use in several ongoing studies of the ecosystem. The proper IACUC permissions to Matich were obtained for the initial study, and all fish in the study were dissected for stomach content analysis. When the fish were collected, lengths (mm) and weights (g) were recorded, along with the habitat salinity (ppt) where the fish were caught. The internal organs (mostly gastrointestinal organs) were removed from each fish after dissection, and frozen in bags labelled with an identification number. The descriptive data

were provided along with the specimen's internal organs, which are matched via the animal identification numbers between the data set and the bags of frozen organ matter.

Parasite Collection and Identification

The viscera of each specimen were thawed before necropsy. If present, liver tissue or spleen tissue was separated from the intestinal tissues. The non-intestinal tissue was macerated and examined for helminths. Dissection of the intestines was conducted using the dilution method. Intestines were cut longitudinally, and then placed into a beaker containing at least 250 ml of tap water. Once in the water, the intestines were agitated to dislodge parasites, and then carefully scraped with forceps. The intestines were then examined under a dissecting microscope to remove parasites embedded in the gut lining. If needed, the process was repeated until the guts were observed to be fully cleaned. The water containing the intestinal contents was given ample time for all materials to settle. The top water in the beaker was carefully poured off in a manner that did not disturb the settled material. Enough water was left in the beaker for gut contents to be poured out in small amounts. The water was poured in thin layers into a petri-dish, and observed under a dissecting microscope for parasites, which were then curated for identification and counting.

Nematodes were fixed in glacial acetic acid until the protective cuticle was cleared, and were stored in glycerol, a solution of 70% ethanol and 8% glycerin. Trematodes, cestodes, and acanthocephalans were fixed in formaldehyde or AFA (acid-formalin-ethanol), for at least 15 minutes and stored in 70% ethanol. Representative samples of each species were prepared as permanent slide mounts and stained with Harris

Hematoxylin and eosin counterstain. After proper preparation, parasites were identified and counted.

For initial identification of all parasites to order, family, and occasionally genus, Hoffman and Williams (1999) was used. For nematodes, Arai and Smith (2016) was used to confirm genus and to identify some species. Other species were identified using the following sources: Alarcos et al (2006) Bartlett (1996), Chai et al (2015), Chandler (1935), Deardorff and Overstreet (1980a), Deardorff and Overstreet (1981), Fusco and Overstreet (1978), Jilek and Crites (1982), Koie (2001), Moravec et al (1997), Moravec et al (2011), Moravec et al (2019), and Timi and Sardella (1982). For trematodes, Hendrix and Overstreet (1977), Hopkins (1941) and Simpson and McGraw (1979) were used for species descriptions of those species that could be identified further than the Hoffman and Williams (1999) key. For acanthocephalans, Amin (1998) was used for confirming generic identification, and for species identifications the following were used: Amin (1975), Amin and Huffman (1984), Amin and Van Ha (2011), Bullock (1966), and Kohn and Macedo (1984). For cestodes, most could not be identified to species so Hoffman and Williams (1999) was used as the primary source for identification, but one additional species description, Overstreet (1977), was used.

Statistical Analysis

To describe the parasite infracommunity in each host, the prevalence, mean intensity, and mean abundance of parasites were calculated for each parasite population using QPweb (Reiczigel et al 2019). Prevalence (%) tells how often each host is, or is not, infected with a particular parasite species (Bush et al. 1997). Mean intensity describes the average intensity of a parasite species in a host, where intensity is the

number of individuals of one parasite species in a single host (Bush et al. 1997). Mean abundance is the total number of parasite individuals of one species divided by the total number of examined hosts, infected and uninfected (Bush et al. 1997). Mean intensity and mean abundance are both reported with their respective standard errors.

To investigate the effects of host size and habitat salinity on the parasite community of fishes the intensity of infection and level of diversity were calculated. Intensity refers to the number of parasitic individuals of one species that are infecting a single host, essentially a count of the parasite per host (Bush et al. 1997). For this study, the total intensity of infection, intensity of each parasite, added together for each host fish, was the desired metric for comparison with host size. The Shannon-Weiner index was used to measure diversity, and values were calculated using the *vegan* package (Oksanen et al. 2020). Linear modeling (regression) was conducted to quantify how the communities shift with host size and habitat salinity variables. All statistical analyses were completed using the statistical program R (R Core Team 2021).

Before completing any comparative statistics, the prevalence, mean intensity, and mean abundance were compared between species via t-test using the *stats* package (R Core Team 2021). Several methods were applied for the comparison of the black drum parasite communities to the red drum parasite communities, including Jaccard's index (J_i), numerical dominance index (D_i), Hutcheson t-test, and Percent similarity index (PS_i). Jaccard's index (J_i) was used to evaluate the similarity of parasite species that are shared between the two drum species (Jaccard 1912) such as:

$$J_i = C / (S_1 + S_2) - C$$

Where C = the number of parasite species common to both host communities, S_1 = the number of parasite species in host community 1, and S_2 = the number of parasite species in host community 2.

The D_i was used to determine if any one species of parasite is numerically dominant in the host community (Leong and Holmes 1981) using:

$$D_i = (A_i / A_t) * 100$$

Where A_i = total number of individuals within a parasite species i, and A_t = the total number of all parasite individuals found in the host sample. These values were compared qualitatively between the species.

The Hutcheson t-test (Hutcheson 1970) was designed specifically for comparing Shannon-Wiener diversity between two sites. For this study, black drum was treated as site a, and red drum as site b. The formulas used for these calculations are as follows:

$$t = \frac{H_a - H_b}{\sqrt{s^2{}_{Ha} + s^2{}_{Hb}}}$$

$$s^2{}_H = \frac{\sum p * (\ln p)^2 - (\sum p * \ln p)^2}{n} + \frac{s-1}{2n^2}$$

Where t=Hutcheson t test statistic, H_a= Shannon-Wiener index of sample a, H_b= Shannon-Wiener index of sample b, s^2_{Ha}= the variance of sample b, p= the proportion of each parasite species, n= total abundance, and s= species richness (number of species).

PS_i (Krebs 1989) was used to compare the proportion of black drum parasites to red drum parasites between the different size classes and salinity classes. The following equation was used:

$$PS_i = \sum \text{minimum } (P_{1i}, P_{2i})$$

Where PS_i= percent similarity between sample 1 and sample 2, P_{1i}= percent of species i in community sample 1, and P_{2i}= percent of species i in community sample 2. The total lengths (mm) of all fish were sorted into small, medium, and large groups based on the values for their species, and then PS_i was calculated between each possible grouping. The same procedure was done with the habitat salinities for all fish sorted into low, moderate, and high groups.

To further address the effects of host size and habitat salinity on the combined communities, mixed-effect modeling was used (Zuur et al. 2009, R Core Team 2021). This test seeks to model how the diversity of the parasite communities are affected collectively by host size and habitat salinity. The effect of fish species on the data cannot be ignored as a factor, so mixed modelling is required. Furthermore, mixed modelling can account for the nestedness of the data. Mixed-effect modelling allows for both continuous and discrete variables to be run within the same model, which should give the best possible model for the data set.

CHAPTER III

Results

Before results could be calculated for this study, some gaps in the size data had to be extrapolated. Samples for the present study were selected to optimize the range of salinities, which required the selection of some fishes with missing total length and weight data points. Regressions were calculated using all available data for both drum species collected from Sabine Lake. The black drum data set was composed of 94 total individuals from which 59 individuals were sampled for this study. Of these 59 selected individuals, there were 8 total lengths missing. The length and weight data plotted for black drum appear to be linear with few points deviating from the trendline (Figure 3). According to Murphy and Taylor (1989) the growth of black drum is isometric, therefore a linear regression of total length to weight was anticipated. Total length regressed against weight was statistically significant ($R^2 = 0.87$, length = 0.1623*weight+244.55). The 8 missing total lengths were calculated using this significant relationship.

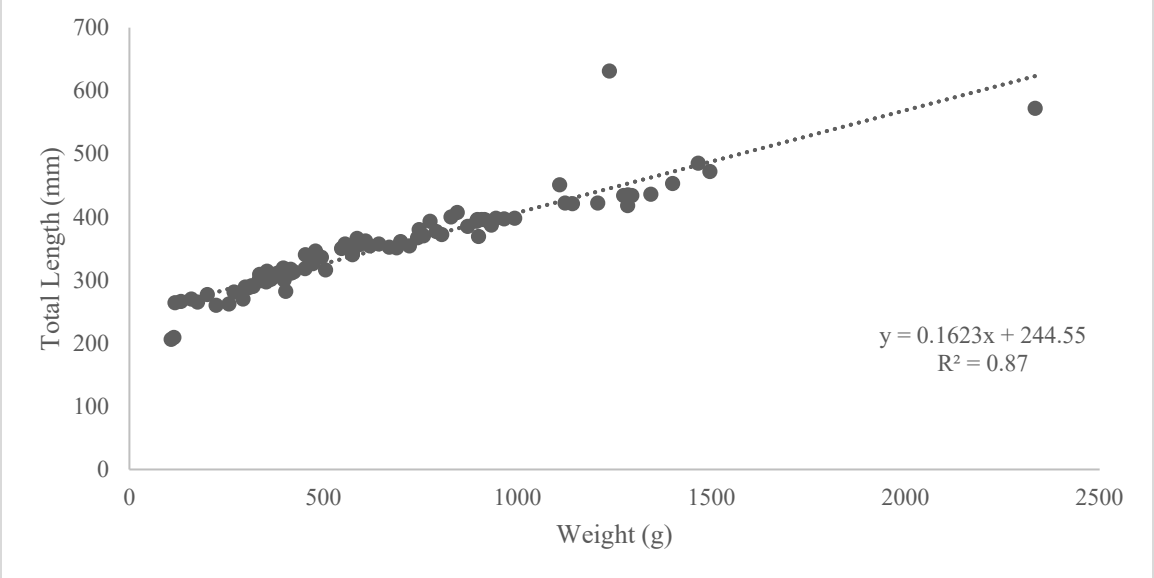

Figure 3. *Total Length(mm) Regression of Black Drum.* Note: A graph representing the linear regression comparing length (mm) and weight (g) data for Sabine Lake black drum (94 individuals). The coefficient of determination and equation for the line are displayed.

The red drum data set was composed of 133 total individuals from which 61 individuals were sampled for this study. Of these 61 selected individuals, there were 4 weights (g) and 1 total length (mm) missing. When plotted, the weight and length relationship red drum data showed an exponential trend (Figure 4), and the length to weight plot showed the opposite logarithmic trend (Figure 5). The exponential trend (Figure 4) is similar to the growth curve found by Overstreet (1983) for juvenile red drum in Mississippi. Weight regressed against total length was statistically significant (R^2 = 0.94, weight = $49.548e^{0.0063*length}$). Total length regressed against weight was also statistically significant (R^2 = 0.94, length = 148.84ln(weight) - 556.35). The missing values were calculated using these significant relationships.

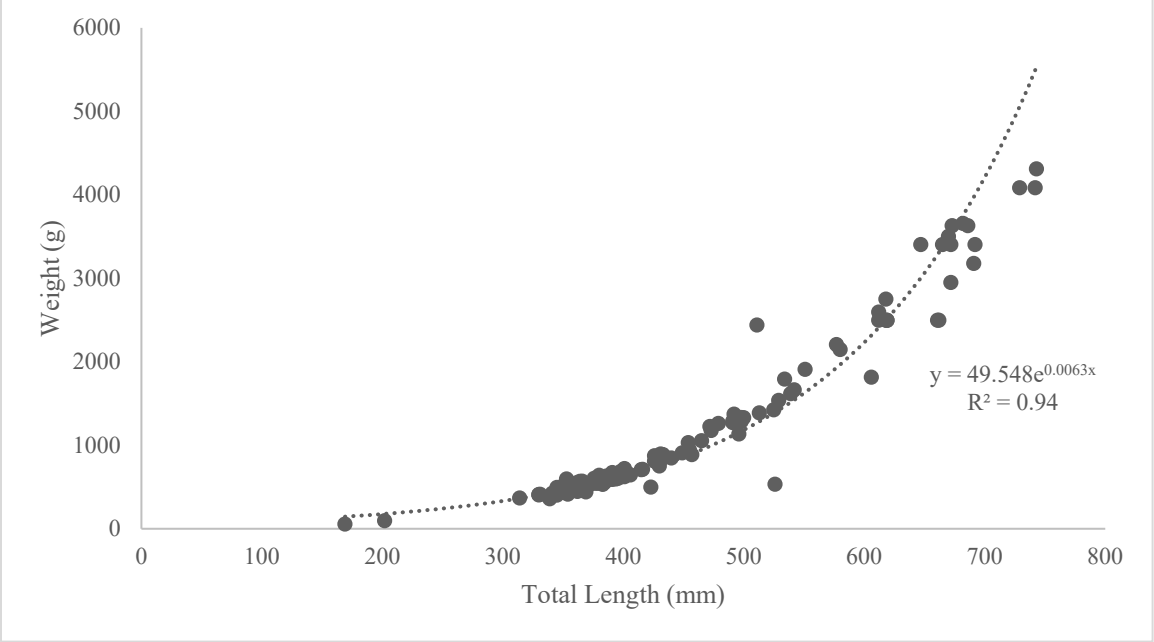

Figure 4. *Weight(g) Regression of Red Drum.* Note: A graph representing the regression comparing weight (g) and length (mm) data for Sabine Lake red drum (133 individuals). The coefficient of determination and equation for the line are displayed.

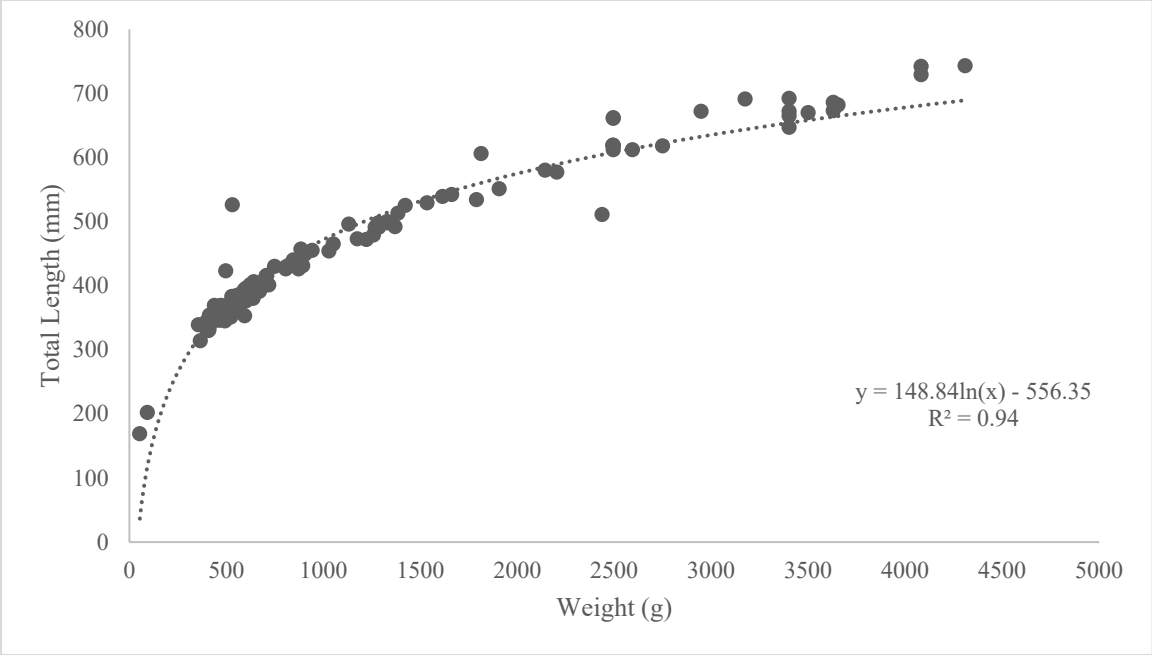

Figure 5. *Total Length(mm) Regression of Red Drum.* Note: A graph representing the regression comparing length (mm) and weight (g) data for Sabine Lake red drum (133 individuals). The coefficient of determination and equation for the line are displayed.

Black Drum Parasite Community

For this study 59 black drum viscera were necropsied, 54 of which were parasitized and 5 of which were unparasitized. In the 54 parasitized fish, 1250 individual parasites were found representing 16 species. These 16 species included 8 nematode species (1167 individuals), 4 trematode species (56 individuals), 2 acanthocephalan species (22 individuals), and 2 cestode species (5 individuals). Nematodes were the predominate parasitic type representing 93.36% of the community. Trematodes, acanthocephalans and cestodes made up 4.48%, 1.76%, and 0.40% of the community respectively (Table 2).

The prevalence of the parasites ranged from 69.5% to 1.70%. The mean intensity ranged from 12.49 to 1.00. The mean abundance ranged from 7.41 to 0.02. *D. mariajuliae* was the most prevalent species in black drum at 69.5%, but was second for

mean intensity (8.37) and mean abundance (5.81). *Dichelyne minutus* had the highest mean intensity (12.49) and mean abundance (7.41) but was second in prevalence (59.3%). *Gnathostoma spinigerum,* larval trematode sp.2, and nematode sp. had the lowest prevalence value of 1.70%, but only *G. spinigerum* and nematode sp. shared the lowest mean abundance value of 0.02. The lowest mean intensity value of 1.00 was shared by the following five parasites: *G.spinigerum, Hysterothylacium* sp. 1, larval cestode sp. 1, nematode sp., and trematode sp.

Table 2. *Population Indices for Parasites of 59 Black Drum Collected from Sabine Lake*

Parasite Species	Prevalence (%)	Mean Intensity (±SE)	Mean Abundance (±SE)
Capillaria sp.	55.9	5.91 (±1.52)	3.31 (±0.93)
Contracaecum multipapillatum, L	39.0	7.61 (±2.02)	2.97 (±0.92)
Cotylogaster basiri	20.3	1.42 (±0.42)	0.29 (±0.11)
Cotylogaster dinosoides	35.6	1.67 (±0.25)	0.59 (±0.14)
Dichelyne mariajuliae	69.5	8.37 (±1.55)	5.81 (±1.19)
Dichelyne minutus	59.3	12.49 (±4.95)	7.41 (±3.03)
Dichelyne sp.2	8.50	2.60 (±1.12)	0.22 (±0.13)
Dollfusentis chandleri	18.6	1.64 (±0.24)	0.31 (±0.09)
Echinorhynchida larvae	5.10	1.33 (±0.33)	0.07 (±0.04)
Gnathostoma spinigerum, L	1.70	1.00 (±0)	0.02 (±0.02)
Hysterothylacium sp.1*, L*	3.40	1.00 (±0)	0.03 (±0.02)
Larval Cestode sp.1	3.40	1.00 (±0)	0.03 (±0.02)
Larval Cestode sp.2	3.40	1.50 (±0.50)	0.05 (±0.04)
Larval Trematode sp.2	1.70	2.00 (±0)	0.03 (±0.03)
Nematode sp.	1.70	1.00 (±0)	0.02 (±0.02)
Trematode sp.	3.40	1.00 (±0)	0.03 (±0.02)

Note: Mean intensity and mean abundance are reported with standard error (±SE) Larval species are indicated with an *L* unless the species is named as larval.

There is a relationship between intensity of infection and total length (mm) for black drum (Figure 6). The black drum data appear to be more clustered at smaller lengths with an increase in spread as size increases (Figure 6). The data point at a length greater than 600 mm and an intensity around 250 could be considered an outlier as it is at

a considerably higher intensity than any other point (Figure 6). However, this point was kept in the data set because there cannot be certainty about whether it is a true outlier due to the lack of other fish of the same length in the data set. This data appears to show an increase of intensity as total length (mm) of the fish increases, but the data points show some spread. The regression of intensity of infection against host total length was significant (R^2=0.29, p<0.05). The hypothesis that parasitic intensity increases as host size increases is supported for black drum, and the model explains 29% of the variation within the data.

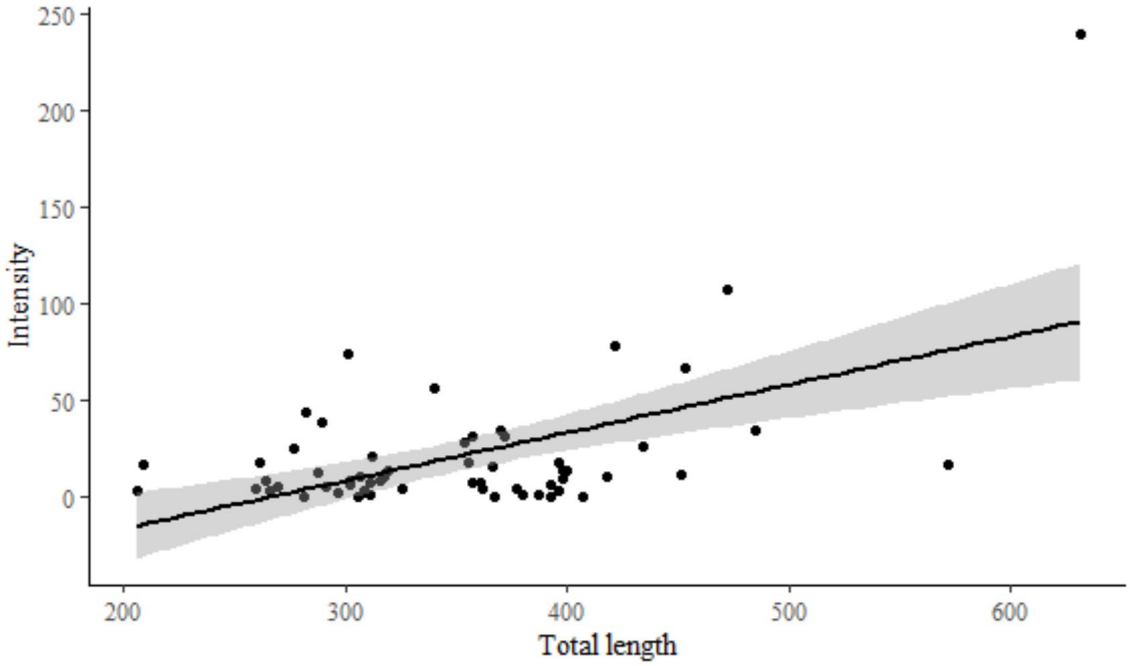

Figure 6. *Intensity of Parasitic Infection v Total Length (mm) of 59 Black Drum from Sabine Lake.* Note: Intensity of infection is the total count of all parasites found per fish, and total length was recorded for hosts at the time of capture. The trendline, with error (light grey), is shown for the regression (R^2=0.29, p<0.05).

There is no clear relationship between Shannon-Wiener diversity and habitat salinity for Sabine Lake black drum (Figure 7). Diversity regressed against salinity was not statistically significant (R^2=0.01, p=0.39). The salinity from which a host is collected, and the diversity of the parasites found in that host are not correlated. The lack in

continuity from low to high salinity values, and a bias toward low salinity samples may have affected the model (Figure 7).

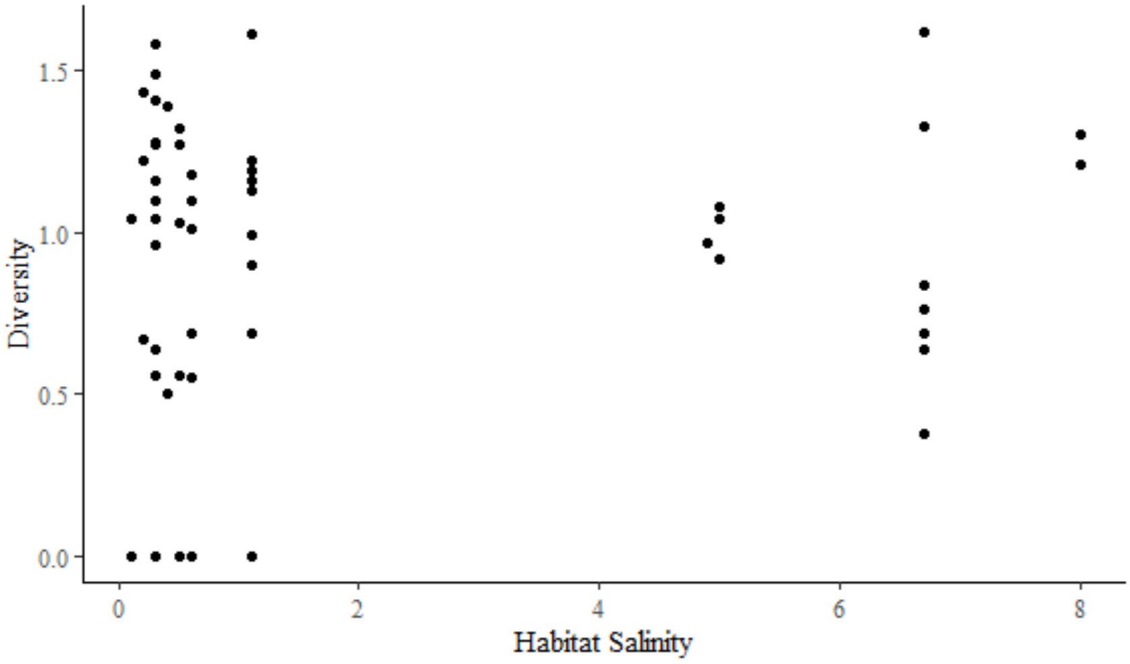

Figure 7. *Diversity of Parasites v Habitat Salinity (ppt) of 59 Black Drum Collected from Sabine Lake.* Note: Diversity is Shannon-Weiner Index calculated for parasite community of each fish. Habitat salinity was recorded at the time of fish collection.

Red Drum Parasite Community

For this study 61 red drum viscera were necropsied all of which were parasitized by at least one species. In these fish, 3408 individual parasites were found representing 33 species. These 33 species comprised 20 nematode species (2438 individuals), 4 trematode species (475 individuals), 5 acanthocephalan species (40 individuals), and 4 cestode species (455 individuals). Nematodes were the predominate parasitic type representing 71.54% of the community. Trematodes, acanthocephalans and cestodes made up 13.94%, 1.17%, and 13.35% of the community respectively. Although acanthocephalans made up the smallest percentage of the community, this group had five species, one more than both cestodes and trematodes (Table 3).

Prevalence values ranged from 90.2% to 1.60%, mean intensity ranged from 36.00 to 1.00, and mean abundance values ranged from 18.07-0.02. The highest prevalence for red drum occurred in both *Contracaecum multipapillatum* and *Dichelyne fastigatus*, and the lowest prevalence value occurred in the following species: *Contracaecum* sp*., Gorgorhynchus medius, Spinitectus* sp.2*,* larval cestode sp.1, larval trematode sp.2, Raphidascarinae sp., and the Trypanorhynca larvae. The species with the highest mean intensity was *D. leiostomi* and the lowest mean intensity occurred in each of the following species: *Acanthocephalus dirus*, *Contracaecum* sp., *Cotylogaster dinosoides*, Larval Cestode sp.1, Larval Trematode sp.2, *Poecilancistrium caryophyllum*, Raphidascarinae sp., and Trypanorhynca larvae. The highest mean abundance was in *C. multipapillatum* and the lowest mean abundance occurred in the following species: *Contracaecum* sp., larval cestode sp.1, larval trematode sp.2, Raphidascarinae sp., and Trypanorhynca larvae.

Table 3. *Population Indices for Parasites of 61 Red Drum Collected from Sabine Lake*

Parasite Species	Prevalence (%)	Mean Intensity (±SE)	Mean Abundance (±SE)
Acanthocephalus dirus	3.30	1.00 (±0.00)	0.03 (±0.02)
Capillaria sp.	26.2	3.00 (±0.76)	0.79 (±0.26)
Contracaecum multipapillatum, L	90.2	20.04 (±4.89)	18.07 (±4.47)
Contracaecum rudolphii, L	6.60	4.75 (±3.75)	0.31 (±0.26)
Contracaecum sp., *L*	1.60	1.00 (±0.00)	0.02 (±0.02)
Cotylogaster dinosoides	3.30	1.00 (±0.00)	0.03 (±0.02)
Dichelyne fastigatus	90.2	15.09 (±2.68)	13.61 (±2.48)
Dichelyne minutus	41.0	7.88 (±1.88)	3.23 (±0.91)
Dichelyne sp.1	6.60	2.25 (±0.48)	0.15 (±0.08)
Dichelyne szidati	13.1	7.88 (±2.46)	1.03 (±0.46)
Diplomonorchis leiostomi	21.3	36.00 (±26.29)	7.67 (±5.75)
Dollfusentis chandleri	21.3	1.46 (±0.22)	0.31 (±0.09)
Echinorhynchida larvae	11.5	1.57 (±0.43)	0.18 (±0.08)
Gorgorhynchus medius	1.60	4.00 (±0.00)	0.07 (±0.07)
Hysterothylacium reliquens, L/A	19.7	2.42 (±0.65)	0.48 (±0.17)
Hysterothylacium sp.1, *L*	9.80	3.00 (±0.73)	0.30 (±0.13)
Hysterothylacium sp.2, *L*	6.60	5.00 (±0.33)	0.33 (±0.05)
Hysterothylacium sp.3, *L*	4.90	1.67 (±0.00)	0.08 (±0.05)
Hysterothylacium sp.4, *L*	3.30	2.00 (±4.00)	0.07 (±0.28)
Larval Cestode sp.1	1.60	1.00 (±0.00)	0.02 (±0.02)
Larval Cestode sp.2	23.0	32.14 (±20.28)	7.38 (±4.85)
Larval Trematode sp.1	3.30	2.00 (±0.00)	0.07 (±0.05)
Larval Trematode sp.2	1.60	1.00 (±0.00)	0.02 (±0.02)
Nematode sp.	8.20	1.40 (±0.30)	0.11 (±0.06)
Octospiniferoides chandleri	4.90	1.33 (±0.33)	0.07 (±0.04)
Poecilancistrium caryophyllum, L	3.30	1.00 (±0.00)	0.03 (±0.02)
Raphidascarinae sp., *L*	1.60	1.00 (±0.00)	0.02 (±0.02)
Spinitectus sp.1	6.60	3.75 (±1.60)	0.25 (±0.15)
Spinitectus sp.2	3.30	1.50 (±0.50)	0.05 (±0.04)
Spirocamallanus cricotus	21.3	3.77 (±1.40)	0.8 (±0.35)
Spirocamallanus halitrophus	8.20	1.80 (±0.58)	0.15 (±0.08)
Spirocamallanus sp.	8.20	1.80 (±0.80)	0.15 (±0.09)
Trypanorhyncha larvae	3.30	1.00 (±0.00)	0.03 (±0.02)

Note: Mean intensity and mean abundance are reported with standard error (±SE). Larval species are indicated with an *L* unless the species is named as larval. Species that were found as adults and larvae are indicated with *L/A*.

There is a relationship between intensity of infection for each red drum and total length (mm) for each fish (Figure 8). The red drum data appear to show a slight increase in intensity as total length increases, but there does appear to be an outlier point at an intensity greater than 400 (Figure 8). Other data points for similar sizes do not show such large intensity values. However, there are departures from the clustering at smaller sizes as well, and even though these departures are not as large, the outlier point should not be removed. Intensity of infection regressed against host total length is statistically significant (R^2=0.16, $p<0.05$). The hypothesis that parasitic intensity increases as host size increases is supported for red drum, and the model explains 16% of the variation within the data.

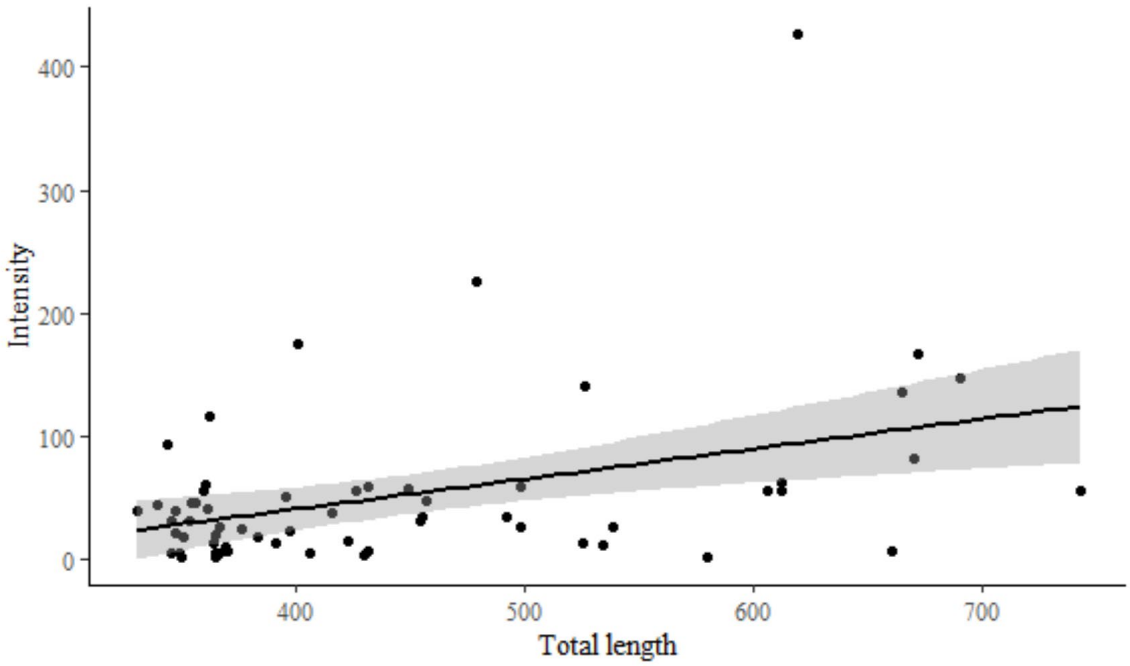

Figure 8. *Intensity of Parasitic Infection v Total Length (mm) of 61 Red Drum from Sabine Lake.* Note: Intensity of infection is the total count of all parasites found per fish, and total length was recorded for hosts at the time of capture. The trendline, with error (light grey), is shown for the regression (R^2=0.16, $p<0.05$).

There is no clear relationship between Shannon-Wiener diversity and habitat salinity for Sabine Lake red drum (Figure 9). The red drum data shows similar spread in diversity at low (> 2.0 ppt) salinity values (Figure 9) to that seen in the data set of black drum (Figure 7). All red drum data not at the low salinity shows a spread of diversity values (Figure 9), which was not seen in the black drum data that had more clustered diversities (Figure 7). However, for the red drum data diversity values do not surpass 1.25 in higher salinities (> 2.0 ppt), this is only seen in the low salinity data (Figure 9). This trend differs from that seen in the black drum data which had diversity above 1.25 in salinities higher than 2.0 ppt (Figure 7). The salinity values for the red drum data show the same lack of continuity as the salinity data of the black drum. Diversity regressed against salinity was not statistically significant (R^2=0.05, p=0.10). The salinity from which a host is collected, and the diversity of the parasites found in that host are not correlated.

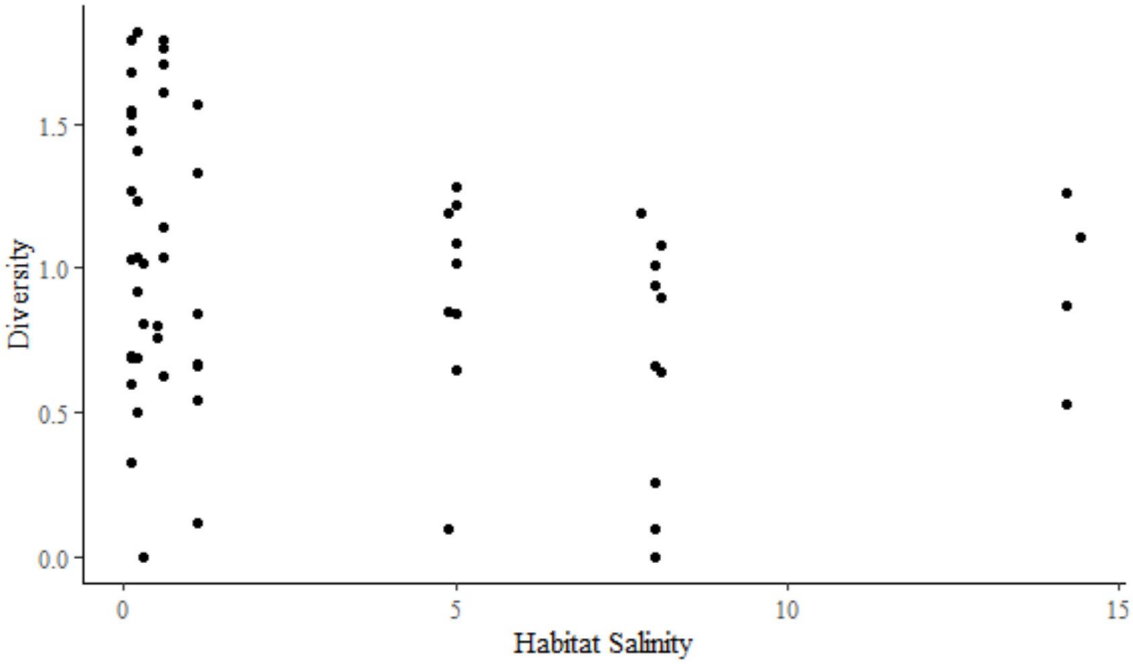

Figure 9. *Diversity of Parasites v Habitat Salinity (ppt) of 61 Red Drum Collected from Sabine Lake.* Note: Diversity is Shannon-Weiner Index calculated for parasite community of each fish. Habitat salinity was recorded at the time of fish collection.

Comparing the Parasite Communities

The combined communities of black and red drum contain 38 different parasite species and 4658 individuals. The combined communities represent 23 nematodes, 6 trematodes, 5 acanthocephalans, and 4 cestodes. However, of the 38 parasite species only 11 parasite species were shared between the two drum species. The shared species include 5 nematodes, 2 trematodes, 2 acanthocephalans, and 2 cestodes. The Jaccard index value was calculated to be 0.2895, or 28.95% similarity between the communities.

Prevalence, Mean Intensity, and Mean Abundance

The prevalence of parasites between red drum and black drum have different ranges, but were not significantly different (t-test, p=0.38). The higher prevalence value of 90.2% occurs twice for red drum and this value is 20.7% higher than the highest black drum prevalence. However, the lowest prevalence values of the parasites in both fish are

only separated by a difference of 0.10%. There are more low prevalence values than high ones in both fish, which is likely what keeps them from being statistically different.

Mean intensity and mean abundance, with standard error, of all parasites from both the black and red drum were compared (Figure 10, Figure 11). Much like the patterns in prevalence there are larger mean intensity and mean abundance values for some parasites in red drum, but there is a large pool of low values for parasites in both fish. The standard error is larger for *D. leiostomi* than any other parasite species due to a sample of 347 individuals from one host fish (Figure 10 and Figure 11); the next largest sample of *D. leiostomi* was 61 individuals. A similar situation resulted in large standard error for larval cestode sp.2 in the red drum, but this was not seen for larval cestode sp.2 in the black drum (Figure 10). Mean intensity values compared between parasite species of black drum and red drum were not significantly different (t-test, $p=0.27$). Mean abundance values compared between parasite species of black and red drum were not significantly different (t-test, $p=0.77$).

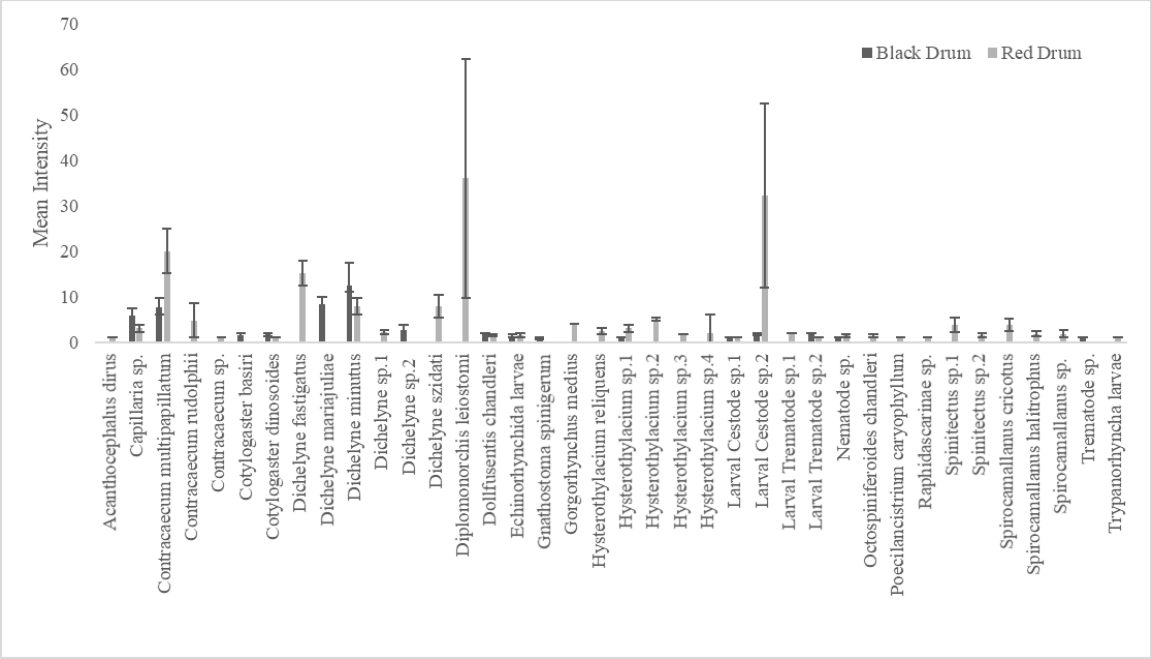

Figure 10. *Comparison of Mean Intensities (±SE) Calculated for All Black and Red Drum Parasites*. Note: The graph shows the mean intensity calculated for all parasites found in the 59 black and 61 red drum collected from Sabine Lake. Dark grey bars are black drum parasites and light grey are red drum parasites. Error bars are calculated standard error.

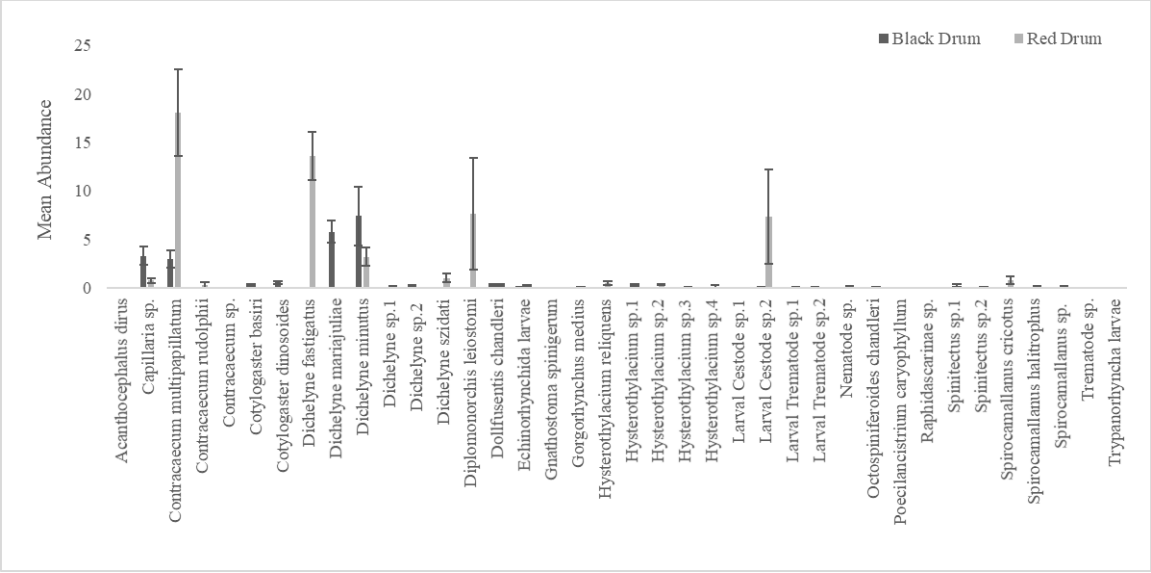

Figure 11. *Comparison of Mean Abundances (±SE) Calculated for All Black and Red Drum Parasites*. Note: The graph shows the mean abundance calculated for all parasites found in the 59 black and 61 red drum collected from Sabine Lake. Dark grey bars are black drum parasites and light grey are red drum parasites. Error bars are calculated standard error.

Numerical Dominance, Hutcheson t, and Percent Similarity

Comparing the numerical dominance values of black and red drum showed that black drum parasites had higher dominance values overall (Table 4). This is likely due to the vast difference in species richness, 16 species (black drum) versus 33(red drum) and number of parasites found, 1250 (black drum) versus 3408 (red drum). The most dominant parasites in black drum were *D. minutus, D. mariajuliae, Capillaria* spp., and *C. multipapillatum*; for red drum they were *C. multipapillatum, D. fastigatus, D. leiostomi,* and larval cestode sp. 2. The only species that showed a large dominance value for both fish is *C. multipapillatum*, but it is the fourth most dominant in black drum at 14.00%, and the most dominant in red drum at 32.34%. *Dichelyne minutus* and *Capillaria* spp. are species shared by both drums, but they do not have large dominance values in red drum (5.78 and 1.41%) like they do in black drum (34.96 and 15.60%). Larval cestode sp. 2 is also found in both fish, but it is much more dominant in the red drum community (13.20%) than the black drum community (0.24%). Echinorhynchida larvae are the only shared species that had the same level of dominance in both fish, though it was not very dominant at just 0.32%.

Table 4. *Numerical Dominance of Parasites found in Black and Red Drum from Sabine Lake*

Parasite Species	D_i Black Drum	D_i Red Drum
Acanthocephalus dirus	0.00	0.06
Capillaria sp.	15.60	1.41
Contracaecum multipapillatum, L	14.00	32.34
Contracaecum rudolphii, L	0.00	0.56
Contracaecum sp., *L*	0.00	0.03
Cotylogaster basiri	1.36	0.00
Cotylogaster dinosoides	2.80	0.06
Dichelyne fastigatus	0.00	24.35
Dichelyne mariajuliae	27.44	0.00
Dichelyne minutus	34.96	5.78
Dichelyne sp.1	0.00	0.26
Dichelyne sp.2	1.04	0.00
Dichelyne szidati	0.00	1.85
Diplomonorchis leiostomi	0.00	13.73
Dollfusentis chandleri	1.44	0.56
Echinorhynchida larvae	0.32	0.32
Gnathostoma spinigerum, L	0.08	0.00
Gorgorhynchus medius	0.00	0.12
Hysterothylacium reliquens, L/A	0.00	0.85
Hysterothylacium sp.1, *L*	0.16	0.53
Hysterothylacium sp.2, *L*	0.00	0.15
Hysterothylacium sp.3, *L*	0.00	0.12
Hysterothylacium sp.4, *L*	0.00	0.59
Larval Cestode sp.1	0.16	0.03
Larval Cestode sp.2	0.24	13.20
Larval Trematode sp.1	0.00	0.12
Larval Trematode sp.2	0.16	0.03
Nematode sp.	0.08	0.21
Octospiniferoides chandleri	0.00	0.12
Poecilancistrium caryophyllum, L	0.00	0.06
Raphidascarinae sp., *L*	0.00	0.03
Spinitectus sp.1	0.00	0.44
Spinitectus sp.2	0.00	0.09
Spirocamallanus cricotus	0.00	1.44
Spirocamallanus halitrophus	0.00	0.26
Spirocamallanus sp.	0.00	0.26
Trematode sp.	0.16	0.00
Trypanorhyncha larvae	0.00	0.06

Note: D_i is the calculated numerical dominance index value for the parasite. Any 0.00 value indicates a parasite that as not found in that host fish. Larval species are indicated with an *L* unless the species is named as larval. Species that were found as adults and larvae are indicated with *L/A*.

There was a significant difference between the parasitic diversity of the black and red drum (Hutcheson t-test $p<0.05$, Figure 12). The red drum parasite community is significantly more diverse than the black drum parasite community (Figure 12). This difference is driven by the difference in richness and parasite counts for the two drum species. There was 2000+ more parasitic individuals in the red drum with 17 more species, so the value of H for red drum was much higher than the H of black drum.

Hutcheson t-test		
Species:	Black Drum	Red Drum
Total	1250	3408
Richness	16	33
H	1.639935756	1.941501818
S^2_H	0.000692602	0.000413582
Statistical Output		
t	9.067107272	
df	2819.788554	
Crit	1.960805869	
p	2.23208E-19	
CI	0.052634657	0.040673448

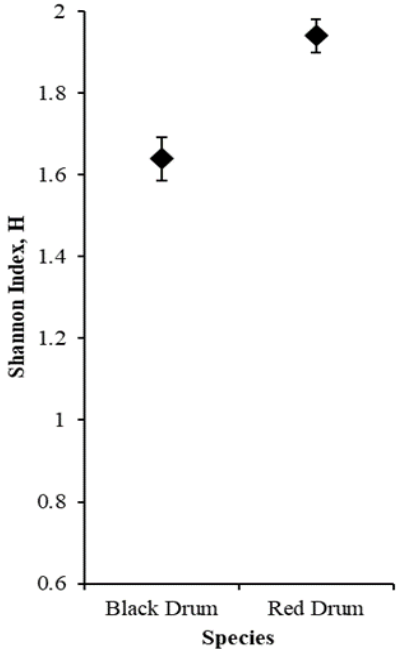

Figure 12. *Hutcheson T-test Comparing Parasitic Diversity of Black and Red Drum from Sabine Lake.* Note: The table shows the statistical output of the Hutcheson t-test, and the graph depicts the Shannon-Wiener index (H) values with the associated error.

For percent similarity calculations between sizes, the total length (mm) of fish was used as the metric for host size, and the data was separated into small, medium, and large categories based on the range of size for each fish. For the red drum small fish were defined as being 300-450 mm in length, medium 451-600 mm, and large 601-750 mm. For black drum the small fish were 200-350 mm, medium 351-500 mm, and large 501-

650 mm. The size categories were created separately for each fish because the fish do not grow at the same rates, and do not hatch at the same times (Table 5).

Table 5. *Percent Similarity of Parasite Communities Compared Between Host Size Classes*

	Small (Red Drum)	Medium (Red Drum)	Large (Red Drum)
Small (Black Drum)	56.82*	52.44	42.74
Medium (Black Drum)	25.86	22.12	36.36
Large (Black Drum)	11.90	8.01*	22.84

Note: Starred values are the highest and lowest percent similarities. Size classes are as follows: small (red) 300-450 mm, medium (red) 451-600 mm, large (red) 601-750 mm, small (black) 200-350 mm, medium (black) 351-500 mm, and large (black) 501-650 mm.

The highest similarity was between parasite communities of small fish in both species, and the lowest was between medium red drum and large black drum parasite communities. Percent similarity remained high for comparisons of the small black drum community to both medium and large red drum parasite communities. Some of this can be explained by the fact that most black drum fell into the small size category, whereas the red drum were more spread between the size categories, though they are also biased toward small fish sizes.

For percent similarity calculations between habitat salinity (ppt) categories the data was separated into low, moderate, and high categories based on the range of salinities of both samples. The ranges for the categories are as follows: low- 0-2.9 ppt, moderate- 3.0-7.9 ppt, and high- 8.0-14.9 ppt (Table 6). These categories were not treated separately because the fish came from the same ecosystem, Sabine Lake. The highest similarity was between low salinity parasite communities of both fish, the same as was seen for size. However, for salinity categories, the high salinity parasite communities of both fish species show the lowest percent similarity.

Table 6. *Percent Similarity of Parasite Communities Compared Between Habitat Salinities*

	Low (Red Drum)	Moderate (Red Drum)	High (Red Drum)
Low (Black Drum)	39.80*	32.66	32.90
Moderate (Black Drum)	35.06	28.58	29.22
High (Black Drum)	17.60	10.36	9.91*

Note: Starred values are the highest and lowest percent similarities. Habitat salinity was recorded for each host individual at the time of collection. Salinities were binned as follows: low 0.0-2.9 ppt, moderate 3.0-7.9 ppt, and high 8.0-14.9 ppt.

These percent similarities also do not show the pattern of low salinity black drum parasite communities having the highest similarity across the matrix. For salinity, moderate black drum and low red drum communities have the second highest percent similarity, and high red drum and low black drum show the third highest similarity between communities.

Mixed Effect Model

A mixed effect model was run to see how host size and habitat salinity affect the Shannon-Weiner diversity when black and red drum data are pooled (Figure 13). For this analysis host size and habitat salinity were treated as fixed effects, and the fish species was treated as the random effect. These results show that diversity is not explained by host size, habitat salinity, or the combination of both of these factors (Figure 13). Host size was not modeled against diversity for the fish species individually, but was put into this model because it was hypothesized that increased host size would increase the similarity of parasite diversity; this is not the case.

A)

Mixed Effect Model

Predictors	*Estimates*	*CI*	*p*
(Intercept)	0.68	0.34 – 1.02	**<0.001**
Size	0.00	-0.00 – 0.00	0.125
Salinity	-0.01	-0.03 – 0.02	0.602
Random Effects			
σ^2	0.22		
$\tau_{00\ Species}$	0.00		
$\tau_{11\ Species.Size}$	0.00		
$\tau_{11\ Species.Salinity}$	0.00		
ρ_{01}	-1.00		
	-0.42		
$N_{Species}$	2		
Observations	120		
Marginal R^2 / Conditional R^2	0.023 / NA		

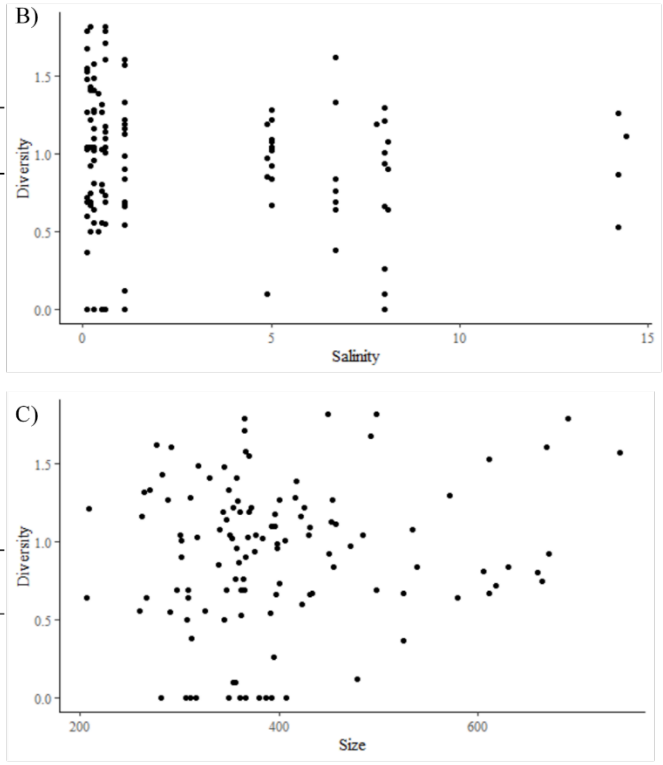

Figure 13. *Mixed Modelling of Parasitic Diversity in Black and Red Drum from Sabine Lake.* Note: A) The statistical output of the mixed model of host size and habitat salinity on Shannon-Wiener diversity index values for 59 black and 61 red drum. B) Scatterplot of diversity v. habitat salinity of both fish species. C) Scatterplot of diversity v. host size for both fish species.

CHAPTER IV

Discussion

Black drum and red drum begin their lives in different habitats within an estuary and consume different types of food items. As both fish grow, they begin to inhabit increasingly similar habitats and feed on more similar prey-items (Sutter et al. 1986). Parasite communities are known to be driven by feeding habits, as many parasites pass between hosts by being consumed (Loker and Hofkin 2015), but diet was not a factor measured in the collection of these fish. Because diet could not be measured, host size and habitat salinity were used as proxies of diet. These factors work as proxies because dietary shifts are known for both fish with increasing body size. Habitat salinity will limit the prey-items available in an area because all aquatic species have a given tolerance to salinity levels and will not exist in waters in which their bodies cannot tolerate the salinity level.

The parasite community of black drum and of red drum were hypothesized to change with increased host size and habitat salinity (Figure 1). Regressions of host size and intensity of parasitic infection was significant for both black and red drum. Larger drums do have larger parasite loads in this ecosystem, which is likely driven by the consumption of prey items because more parasite species were adults, not larvae, in both fish species. There was also a good deal of larval parasite diversity in both hosts, so they are potentially eating eggs from the substrate, or are gaining many larvae via them burrowing into the host body. Regressions of habitat salinity and Shannon-Weiner diversity were not significant for either host species, so salinity is not a driver of diversity in this ecosystem. Diversity of parasites in the red drum is higher than that of black drum

parasites. Most of the life cycles for the parasites found in this study are unknown, so it is impossible to be certain of what is driving the parasitic diversity in either fish species. In any case there is a significant community of parasites in the Sabine Lake ecosystem, which is evidenced by the intensity and diversity of parasites found in these fish.

The parasite community of black drum is less speciose than that of the red drum for this ecosystem. Black drum also had fewer parasites overall and contained the only unparasitized individuals. The parasite community of black drum was dominated by four nematode species: *Capillaria* spp., *C. multipapillatum, D. mariajuliae,* and *D. minutus*, which were also the four most prevalent, had the highest mean intensities and the highest mean abundances. Three of the four species are relatively common and can be found throughout fishes from many families, though they have not been reported specifically from black drum (Arai and Smith 2016, Deardorff and Overstreet 1980a, Koie 2001). The most prevalent parasite collected in this study, *D. mariajuliae*, previously has only been reported from black drum in a single estuary in Argentina (Alarcos et al. 2006). This collection thus represents a new geographical record for *D. mariajuliae* and documentation for this parasite.

Two trematode species also had high prevalence values, but did not have high mean intensity or mean abundance like the other highly prevalent species. These trematodes are *Cotylogaster basiri* and *C. dinosoides*. These parasites were expected to be found in black drum as they are well known from the Gulf of Mexico for this fish (Overstreet et al. 2009). It was, however, unexpected that a few individuals of *C. dinosoides* would be found in the red drum. *Cotylogaster* species have not been recorded in the red drum, so this is a new host record for *C. dinosoides*.

The parasite community of red drum was also dominated by nematodes, but the top four species for prevalence, mean intensity, mean abundance, and numerical dominance were not all nematodes like was found in black drum. *Diplomonorchis leiostomi* and larval cestode sp.2 break the nematode pattern seen in black drum by having high mean intensity, mean abundance, and numerical dominance values due to these species being found at extreme intensity in a few fish. It is also interesting that parasites in the genus *Dichelyne* make it into the top four parasites for both the black and the red drum. *Dichelyne fastigatus* was anticipated for the red drum, but finding other *Dichelyne* species in either fish species was not expected and is an interesting addition to our parasitic knowledge for drum species. The red drum, like the black drum, contained a parasite species that previously had only been documented in Argentina, and, though it was only moderately prevalent in the red drum in this study, more individuals of this species were found from the red drum of this study than from the fish from which the original description stems (Timi and Sardella 2002). *Dichelyne szidati* was originally described parasitizing *Acanthistius brasilianus* (Pisces: Serranidae), so the record of this parasite in this study is both a new locality and a new host record (Timi and Sardella 2002).

Contracaecum multipapillatum is the only parasite species that shares a spot in the four most prevalent, intense, abundant, and numerically dominant parasite species between the two fish species, which is noteworthy because it is a larval species. The life cycle of *C. multipapillatum* is known, but fish can become infected by ingesting infected copepods or by eating other fish that are infected (Huizinga, 1967). The black and red drum both start out eating copepods, so it is likely that they are getting infected when

they are very small fish. However, two larval stages were found in the red drum, so red drum are likely getting infected by consuming other fish as well as consuming copepods.

The parasites of black drum and red drum do not frequently appear in both fish (Appendix). Only two parasites from the Gulf of Mexico were known to be found in both drum species, *D. leiostomi* and *P. caryophyllum* (Simick and Underwood 1996, Matlock 1990, Overstreet 1977). Both of these species were found in this study; however, they were found only in red drum. The fact that *D. leiostomi* was not in both fish could have been driven by feeding habit and habitat difference, but this cannot be stated definitively since these variables were not directly measured for this study. *Poecilancistrium caryophyllum* was not prevalent, not abundant, and occurred at very low intensity in the red drum. Realistically, it may have occurred more frequently in both fish, but it typically occurs in the musculature (not attached to mesentery as it was found here), which was not available for this study (Overstreet 1977). Another parasite, *Gnathostoma spinigerum*, which was found only once in a black drum, is typically found in musculature, and could have had higher abundance and intensity if muscle tissue had been available (Chai et al. 2015). A study searching specifically for this parasite in the Sabine Lake ecosystem may be advisable, as this parasite can cause disease in humans (Chai et al. 2015). Several other species collected in this study previously have not been reported from black and red drum. Prior to this study, only a single species of Acanthocepala had been reported from red drum (see Appendix). However, four species of Acanthocephala were collected in this study, and two of these (the Echinorhynchid larvae and *Dollfusentis chandleri*) were also collected from black drum. *Dollfusentis chandleri* was found multiple times in both fish species, so it is not likely incidental and both fish species represent new host records.

The other two acanthocephalan species, *Gorgorhynchus medius* and *Octospiniferoides chandleri*, were only found once and three time respectively, so there is a chance that they only occur incidentally in these fish.

Despite not detecting considerable overlap of parasites for the Gulf of Mexico in studies before this one (Table 1, Appendix), the fish did share 11 species of parasites. This did not result in high Jaccard index similarity however, because species richness in the red drum was much higher (33) than in the black drum (16). This extreme difference in parasitic diversity was not expected, because the black and red drum are closely related. One of the main hypotheses of this study was that parasite communities would become similar because these two fish species converge into a single habitat and have dietary overlaps in addition to their close relation. verall diversity of the parasite communities was found to be significantly different between the fish species, and prevalence, mean intensity, and mean abundance were not found to be significantly different. So, despite the vast differences in parasite counts and species richness that account for the difference in diversity, the overall communities are comparable in how they are infecting the different fish.

When communities were compared between size classes and salinity levels using percent similarity index, the smallest fishes and the lowest salinity fishes showed the greatest similarity of parasite community, and for salinity the lowest similarity was between communities of high salinity fishes. This pattern seems to oppose the life history of these fish. The mixed effect model did not show host size or habitat salinity to be driving the parasitic diversity in these fish for the Sabine Lake ecosystem. These

relationships say something about these two fish, which may be that they are not eating similar things or may be that they have very different immune responses.

Further study into what parasites are infecting black drum and red drum in shared ecosystems could help to elucidate what is driving the massive discrepancy in species richness for these fish. It is possible that some aspect of Sabine Lake's ecosystem is driving this, but it could also be a pattern seen in these fish everywhere. More studies into the parasite communities of black drum in the Gulf of Mexico, and the rest of the fish's range, would also be advised, as there is very little literature on what parasites might be found in black drum. This study is still significant in that it is the first of its kind in Sabine Lake and provides additional knowledge of parasitism in Gulf of Mexico fishes. Having found two species of parasites previously only reported in Argentina also begs the question of what the range of these parasites may be. Several new studies could be conducted based on the work completed for this project, and hopefully further work can be done for other fishes in the Sabine Lake system.

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APPENDIX

Complete List of Parasites from Black and Red Drum in the Gulf of Mexico and US Atlantic Coast

Parasite Name	Host Species	Location in host	Geographic Distribution	Source(s)
Nematoda				
Ascaris sp.	*Sciaenops ocellatus*	Peritoneum	New Jersey	Matlock 1990; Overstreet 1983
Contracaecum collieri	*Sciaenops ocellatus*	Body Cavity	Texas	Chandler 1935
Contracaecum multipapillatum	*Sciaenops ocellatus*	Mesentery	Mississippi	Overstreet 1983
Contracaecum sp.	*Sciaenops ocellatus*	Mesentery	Florida	Matlock 1990
Dichelyne fastigatus	*Sciaenops ocellatus*	Intestine	Texas, South Carolina	Chandler 1935; Matlock 1990; Moravec et al. 2011
Dichelyne sp.	*Sciaenops ocellatus*	Intestine	North Carolina, Mississippi	Overstreet 1983
Goezia kliksi	*Pogonias cromis*	Stomach	Louisiana	Deardorff and Overstreet 1980b
Goezia pelagia	*Sciaenops ocellatus*	Intestine	Mississippi	Overstreet 1983
Heterakis sp.	*Sciaenops ocellatus*	?	North Carolina	Matlock 1990
Hysterothylacium reliquens	*Sciaenops ocellatus*	Stomach and Intestine	Northern GMex, Mississippi	Overstreet 1983
Philometra floridensis	*Sciaenops ocellatus*	Ovaries	Florida	Moravec et al. 2009
Spirocamallanus circotus	*Sciaenops ocellatus*	Intestine	Mississippi	Overstreet 1983
Cestoda				
Poecilancistrium caryophyllum	*Pogonis cromis, Sciaenops ocellatus*	Musculature	GMex (entire)	Matlock 1990; Overstreet 1977; Overstreet 1983
Poecilancistrium robust(um/us)	*Sciaenops ocellatus*	Intestine	Mississippi, Texas, Florida	Matlock 1990; Overstreet 1983
Pseudogrillotia pleistacantha	*Pogonias cromis*	Musculature	GMex (Northeast and Northwest)	Overstreet 1977

(continued)

Parasite Name	Host Species	Location in host	Geographic Distribution	Source(s)
Rhinebothrium sp.	*Sciaenops ocellatus*	Intestine	Mississippi, Florida	Overstreet 1983
Scolex polymorphus	*Sciaenops ocellatus*	Musculature	North Carolina	Matlock 1990
Scolex sp.	*Sciaenops ocellatus*	Intestine, Pyloric ceca	North Carolina, Mississippi	Overstreet 1983
Tetraphylidia larvae	*Sciaenops ocellatus*	Musculature	North Carolina, Texas	Simick and Underwood 1996
Trematoda (Monogenea)				
Udonella caligorum	*Sciaenops ocellatus*	?	Texas	Overstreet 1983
Trematoda (Digenea)				
Bucephaloides megacirrus	*Sciaenops ocellatus*	Intestine, Pyloric ceca	Texas, Florida, Louisiana, Mississippi	Overstreet 1983; Simick and Underwood 1996
Bucephaloides sp.	*Sciaenops ocellatus*	?	Louisiana	Matlock 1990
Cardicola currani	*Sciaenops ocellatus*	Heart	Mississippi	Bullard and Overstreet 2004
Cardicola palmeri	*Pogonias cromis*	Heart	Mississippi	Bullard and Overstreet 2004
Cotylogaster basiri	*Pogonias cromis*	Intestine, Rectum	Texas, Louisiana, Mississippi	Simpson and Mcgraw 1979
Cotylogaster dinosoides	*Pogonias cromis*	Intestine	Texas, Mississippi, Mexico	Simpson and Mcgraw 1979
Trematoda (Digenea)				
Diplomonorchis leiostomi	*Pogonias cromis, Sciaenops ocellatus*	Intestine, Pyloric ceca	Texas, Louisiana, Mississippi, Florida, Southeastern US	Simick and Underwood 1996
Diostomum areolatum	*Sciaenops ocellatus*	?	North Carolina	Matlock 1990
Diostomum tenue	*Sciaenops ocellatus*	?	North Carolina	Matlock 1990
Diostomum vitellosum	*Sciaenops ocellatus*	?	North Carolina	Matlock 1990
Fimbriatus fimbriatus	*Sciaenops ocellatus*	?	Louisiana	Matlock 1990
Homalometron pallidum	*Pogonias cromis*	Intestine	Florida, Louisiana, Mexico, Southeastern and Northeastern USA, Inland USA	Curran et al. 2012

(continued)

Parasite Name	Host Species	Location in host	Geographic Distribution	Source(s)
Lecithaster confusus	*Sciaenops ocellatus*	Intestine	Texas, Florida, Louisiana, Mississippi	Simick and Underwood 1996
Lecithochirium mecosaccum	*Sciaenops ocellatus*	Stomach	Florida	Overstreet 1983
Metadena spectanda	*Sciaenops ocellatus*	Intestine, Pyloric ceca	Texas, Louisiana, Mississippi	Overstreet 1983
Opecoeloides fimbriatus	*Sciaenops ocellatus*	Intestine, Stomach, Pyloric ceca	Texas, Florida, Louisiana, Mississippi, Southeastern and Northeastern USA	Overstreet 1983
Opecoeloides vitellosus	*Sciaenops ocellatus*	Rectum	Florida, Mississippi, Southeastern USA	Overstreet 1983
Prosorhynchoides caecorum	*Sciaenops ocellatus*	Intestine, Pyloric ceca	Texas, Florida, Louisiana, Mississippi	Simick and Underwood 1996
Stomachicola rubea	*Sciaenops ocellatus*	Musculature	Georgia	Overstreet 1983
Myxozoa				
Henneguya texana	*Pogonias cromis*	Gills	Texas	Joy 1972
Henneguya ocellata	*Sciaenops ocellatus*	Intestinal and Cecal Epithelium	North Carolina, Florida	Matlock 1990; Overstreet 1983
Kudoa hypoepicardialis	*Pogonias cromis*	Heart	Northern GMex	Blaylock et al. 2004
Parvicapsula renalis	*Sciaenops ocellatus*	Kidney	Florida	Landsberg 1993
Arthropods				
Anilocera laticauda	*Sciaenops ocellatus*	?	Texas	Matlock 1990; Overstreet 1983
Balanus improvisus	*Sciaenops ocellatus*	Scales	Mississippi	Overstreet 1983
Caligus annularis	*Sciaenops ocellatus*	Mouth	Georgia	Overstreet 1983
Caligus bonito	*Sciaenops ocellatus*	Body	Texas	Matlock 1990; Overstreet 1983
Caligus haemulonis	*Sciaenops ocellatus*	Mouth	Texas, Louisiana	Matlock 1990; Overstreet 1983
Caligus mutabilis	*Sciaenops ocellatus*	?	North Carolina	Overstreet 1983
Caligus repax	*Sciaenops ocellatus*	?	Texas	Matlock 1990; Overstreet 1983
Caligus sciaenops	*Sciaenops ocellatus*	Gills	Texas	Matlock 1990; Overstreet 1983

(continued)

Parasite Name	Host Species	Location in host	Geographic Distribution	Source(s)
Echetus typicus	*Sciaenops ocellatus*	Gills and Operculum	Texas, Florida, North Carolina, Washington D.C.	Overstreet 1983
Lepophtheirus longipes	*Sciaenops ocellatus*	Gills	Mississippi	Overstreet 1983
Lernaeenicus radiatus	*Sciaenops ocellatus*	Fins	North Carolina, Louisiana, Georgia	Matlock 1990; Overstreet 1983
Arthropods				
Lernanthropus longipes	*Sciaenops ocellatus*	?	North Carolina, Texas	Matlock 1990; Overstreet 1983
Lernanthropus paenulatus	*Sciaenops ocellatus*	Gills	Texas	Matlock 1990; Overstreet 1983
Lernanthropus sp.	*Sciaenops ocellatus*	Gills	Mississippi	Overstreet 1983
Lironeca ovalis	*Sciaenops ocellatus*	Gills	Mississippi	Overstreet 1983
Neobrachiella gulosa	*Sciaenops ocellatus*	Gills, Branchial cavity, and operculum	North Carolina, Georgia, Texas, Louisiana, Florida, Mississippi	Overstreet 1983
Neobrachiella intermedia	*Sciaenops ocellatus*	Gills and Operculum	Florida, Georgia, North Carolina	Overstreet 1983
Nerocila acuminata	*Sciaenops ocellatus*	Fins	Texas, Mississippi	Overstreet 1983
Parabrachiella gulosa	*Sciaenops ocellatus*	Gills and Operculum	Texas, Florida, North Carolina, Washington D.C.	Matlock 1990
Parabrachiella intermedia	*Sciaenops ocellatus*	Gills and Operculum	Florida, North Carolina	Matlock 1990
Sciaenophilus tenuis	*Sciaenops ocellatus*	Gills	Mississippi	Overstreet 1983
Acanthocephala				
Southwellina hispida	*Sciaenops ocellatus*	Mesentery and embedded in gonad	Mississippi	Overstreet 1983
Annelida				
Calliobdella vivida	*Sciaenops ocellatus*	Mouth	Mississippi	Overstreet 1983
Myzobdella lugub(ris/ria)	*Sciaenops ocellatus*	Mouth and Branchial cavity	Mississippi	Matlock 1990; Overstreet 1983

Note: Gulf of Mexico is abbreviated GMex. If location in the body was not listed for a parasite, it is marked with a "?". Geographic distribution refers to recorded locations for the parasite.

VITA

Hannah McNeese

Education

Sam Houston State University Overall GPA: 3.89
Master's, Biology 2018 -2021
Thesis- Comparison of Endohelminth Parasites in Black Drum (*Pogonias cromis*) and Red Drum (*Sciaenops ocellatus*) from the Sabine Lake Estuary

Sam Houston State University Overall GPA: 3.58
Bachelor's, Biology 2014 – 2018
Honors Thesis- Carolina Wren (*Thryothorus ludovicianus*) nest composition in urban and rural habitats

Experience

Supplemental Instructor Aug. 2015 – May 2016
Academic Success Center of Sam Houston State University Huntsville, Texas

- Designed study sessions for students to facilitate understanding of difficult subject matter.
- Trained students to use new methods to study material they have trouble with
- Worked directly with professors to facilitate learning
- Advertised sessions to students via email and through in class speeches

Student Lab Assistant Mar. 2016 – May 2018
Sam Houston State University Biological Sciences Department Huntsville, Texas

- Performed experiment and collected data in the field
- Reviewed and quantified data
- Created spreadsheets
- Performed maintenance on boxes used for bird nesting
- Helped to band birds for the Texas Parks and Wildlife Department

Student Worker at The SHSU Center for Biological Field Studies
Nov. 2016 – May 2018
Sam Houston State University Biological Sciences Department Huntsville, Texas

- Helped conduct a prairie land restoration project
- Helped maintain the property
- Aided in gathering data for ongoing monitoring of the grounds

Lab Instructor/Assistant- Foundations of Science Sept. 2018 – May 2020
Sam Houston State University Biological Sciences Department Huntsville, Texas

- Taught lab sections for Foundations of Science
- Prepped lab materials
- Aided in running lab meetings and preparing new instructors to teach
- Aided in the creation and implementation of new labs to replace outdated material
- Practiced classroom management skills and conflict resolution skills

Research Assistant for National Guard Grant May 2019 – August 2019
Sam Houston State University Biological Sciences Museum Huntsville, Texas

- Sorted insects to order from various traps and stored them appropriately
- Pinned and labeled insects for a museum collection
- Identified Hymenopterans down to family for the collection
- Aided in the final preparation and labeling of Dipteran collections for data reporting

Graduate/Undergraduate Instructor Academy Fellow Oct. 2019 – Feb. 2020
Sam Houston State University Biological Sciences Department Huntsville, Texas

- Helped in designing courses for teaching management skills to student instructors
- Aided in running the event and ensuring smooth flow of courses
- Taught a course on classroom management in the lab setting

Leadership

Active Minds of Sam Houston State University, *Vice President* Spring 2014 – Spring 2018

Symposium- "How to enter Graduate School", *Moderator* Spring 2020

Awards

Patrick Neal O'Bryant Memorial Endowed Scholarship Fall 2016 – Spring 2017

Awarded for Academic Excellence Spring 2016 and Fall 2017

Outstanding Undergraduate Award Spring 2018*Awarded by the SHSU Department of Biology*

Presentations

Poster Presentation April 28th, 2018
Conducted at the SHSU undergraduate research symposium

Carolina Wren (*Thryothorus ludovicianus*) nest composition in urban and rural habitats

Oral Presentation April 28th, 2018
Conducted at the SHSU undergraduate research symposium

Carolina Wren (*Thryothorus ludovicianus*) nest composition in urban and rural habitats

Oral Presentation
April 19th, 2019
Conducted at the TAMUCC 8th Annual Student Research Forum

Comparison of Endohelminth Parasites in Black Drum (*Pogonias cromis*) and Red Drum (*Sciaenops ocellatus*) from the Sabine Lake Estuary

Poster Presentation April 25th, 2019
Conducted at the South Western Association of Parasitologists annual meeting

Comparison of Endohelminth Parasites in Black Drum (*Pogonias cromis*) and Red Drum (*Sciaenops ocellatus*) from the Sabine Lake Estuary