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Feeding ecology and morphometric analysis of paddlefish, *Polyodon spathula*, in the Mermentau River, Louisiana

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FEEDING ECOLOGY AND MORPHOMETRIC ANALYSIS
OF PADDLEFISH, *POLYODON SPATHULA*, IN THE
MERMENEAU RIVER, LOUISIANA

A Thesis

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

in

The Department of Oceanography and Coastal Sciences

by
Nicole Adele Smith
B.S., Louisiana State University, 2001
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ABSTRACT

Little is known about the morphometrics and the feeding ecology of paddlefish in Louisiana. I examined the morphometrics and feeding ecology of paddlefish from the Mermentau River, Louisiana from March 2002 to February 2003.

Paddlefish were examined morphometrically by taking measurements of eye-fork length (EFL), body cavity length (BCL), girth (G), vent girth (VG), mouth vertical (MTB), mouth horizontal (MSS), and mouth gullet bottom (MGB) to determine which parameters would give a better estimate of weight (W). Regression analysis resulted in a morphometric model of the form:

$$\log W = 10.10 + 1.52 (\log EFL) + 1.21 (\log G) + 0.24 (\log VG)$$

($r^2 = 0.97$), though I recommended a more inclusive conservation model of the form:

$$\log W = -9.82 + 1.15 (\log G) + 1.39 (\log EFL) + 0.25 (\log VG) + 0.15 (\log BCL)$$

($r^2 = 0.97$).

Reanalysis of range wide data revealed reservoir/lake paddlefish were generally heavier than river paddlefish at larger eye-fork lengths. This may reflect denser patches of zooplankton in reservoir/lake systems, which may allow for greater paddlefish foraging success than in rivers.

Copepods and cladocerans occurred in 90% and 82% of the stomachs, respectively. Feeding seasonality peaked in summer and winter. Diet appeared to

“switch” from copepods in the summer to cladocerans in the winter. Diatoms dominated most of the full May stomachs. Paddlefish diets were similar between seasons except for the summer and winter seasons. Copepods and cladocerans contributed to most of the similarities and dissimilarities. Paddlefish diets were similar between all stages of sexual maturity with copepods and cladocerans contributing to most of these similarities and dissimilarities. An evaluation of size selectivity using Chesson’s Alpha indicated non-selective feeding and thus paddlefish may be described as indiscriminate planktonic feeders. Calculations of apparent ingestion time indirectly suggest that paddlefish were able to locate dense patches of zooplankton. This study followed the Mississippi Interstate Cooperative Resource Association’s (MICRA) paddlefish studies.

CHAPTER 1

INTRODUCTION

Paddlefish, *Polyodon spathula*, can be described as having a paddle-shaped snout that is one-third the length of the body, long gill rakers, and a nonprotrusible mouth (Bond 1996). They are a primitive species in that they have a predominantly cartilaginous skeleton and smooth skin. They are the only members of the family Polyodontidae residing in North America. The limited record indicates that coastal Louisiana was the historic center of their natural abundance at the turn of the last century (Stockard 1907; Tulian 1916) but that these stocks were quickly overfished despite conservation efforts to limit the harvest of their roe for caviar (Tulian 1916).

Paddlefish are one of the largest living freshwater fishes and are found in only 22 states in North America. They are also one of the oldest living fish species dating back 300 to 400 million years. Longevity is estimated in excess of 50 years. Paddlefish were once an abundant fish in the large rivers throughout the Mississippi River basin and peripheral gulf coast drainages of the central United States (Reed 1989). Habitat degradation combined with overfishing has limited their distribution and reduced the abundance of the paddlefish throughout much of their native range (Carlson and Bonislowsky 1981).

Paddlefish are classified as ram filter feeders ('tow-net' suspension feeders), swimming with their mouth agape and operculum flaps flaring. Adults feed with a large filtering network of gill rakers that are most highly developed on the first gill arch (Gerking 1994). Paddlefish strain crustacean and other zooplankton from the

water column. Rosen and Hales (1981) found that adult paddlefish mainly fed on crustacean zooplankton.

Paddlefish life stages can be defined as larvae, young-of-the-year, juvenile, sub adult, and at the onset of sexual maturity, adult. Paddlefish are considered juveniles until about Age 3. A sub adult is a paddlefish who is older than Age 3 but not yet sexually mature. Male paddlefish may begin maturing as early as Age 4 with 100% of all males being sexually mature by Age 7. Female paddlefish may begin maturing as early as Age 6, 50% are mature by Age 9, and 100% are sexually mature by age 10 (Reed et al. 1992).

Larvae and young-of-the-year less than 150 mm body length (BL) do not have well developed gill rakers and are unable to strain large quantities of zooplankton from the water (Rosen and Hales 1981). They are selective particulate feeders, capturing individual zooplankton one at a time. Some young-of-the-year paddlefish will selectively feed for up to one year and delay switching to filter feeding until after they reach 300 mm BL (Kofkay and Scarnecchia 2002). Larvae and young-of-the-year also differ from adults because they have teeth. Teeth aid larvae and young-of-the-year in eating food until their gill rakers develop.

Once a paddlefish develops its gill rakers, it begins to switch to a filter feeding lifestyle. Michaletz (1982) noted that when paddlefish switch to become filter feeders, the growth rate generally increases because of increased food consumption. Paddlefish use electroreceptors found in the rostrum to help locate prey (Russell 1986; Wilkens et. al. 1997). These electroreceptors help the rostrum act as an antenna to find weak low-frequency electrical currents fields emitted by

zooplankton. The receptors can detect the presence of the zooplankton, as well as the individual feeding and swimming movements of the zooplankton's appendages. Sensory pores extend from the paddle to the top of the head and also to the tips of the operculum. These pores take up nearly half the skin surface of the fish. The rostrum is a guide for the paddlefish to feed because their eyes are poorly developed.

There have been many studies of paddlefish biology in the north-central U.S. (e.g. Hageman et al. 1986; Southall et al. 1984; Rosen et al. 1982), but little research has been done in Louisiana (Reed et al. 1992). Nothing is recorded on the feeding ecology of adult paddlefish in Louisiana other than the early reports of Alexander (1914) and Tulian (1916).

The subsequent Chapters of this thesis investigate a morphometric approach to estimate weight from field measurements (Chapter 2) and examine the feeding habits of sub adult and adult paddlefish in the Mermentau River (Chapter 3). The objectives of Chapter 2 were 1) to determine the best morphometric model correlating weight with various measures of the length and girth of the fish as well as the weights of selected internal organs and 2) to modify the morphometric model into a conservation model using less harmful field measurements. The objectives of Chapter 3 were 1) to conduct identity analysis and size distribution of the prey items by functional groups and 2) investigate the possible effect of season and stage of maturity on the composition of the diet. Chapters 2 and 3 were written as independent manuscripts with their own Introduction, Methods, Results and

Discussion sections. Chapter 4 is a summary of my major findings. Literature citation is found behind Chapter 4 and is a complete citation list for all Chapters.

CHAPTER 2

A MORPHOMETRIC ANALYSIS OF PADDLEFISH IN AN UPPER ESTUARINE SYSTEM OF LOUISIANA

Introduction

Paddlefish *Polyodon spathula*, commonly called spoonbill cat, are a native, naturally dominant, estuarine and freshwater Louisiana fish. When the U.S. instituted a general ban on imports of caviar from Iran and Iraq in the late 1970's, U.S. markets turned to paddlefish to sustain the caviar market. This resulted in a dramatic increase in the harvest of already-stressed Louisiana paddlefish. To protect the remaining Louisiana paddlefish population, the Louisiana Department of Wildlife and Fisheries Commission ratified an emergency closure of state waters to all paddlefish harvest in the spring of 1986. In addition to this closure, research was started to collect life history information on paddlefish in Louisiana waters (e.g. Reed et al. 1992) as part of the Mississippi Interstate Cooperative Resource Association (MICRA). The present research was initiated as an integral component of the MICRA paddlefish stock surveys in Louisiana and at MICRA's recommendation concentrated on the feeding ecology and morphometrics of growth.

As Ricker (1975) notes, it has been found that weight (W) normally varies as a power function of length (L) by the relationship

$$W = aL^b \quad (1)$$

where a and b are constants. Eq. 1 can also be expressed as

$$\log W = \log a + b (\log L). \quad (2)$$

When a fish exhibits a generally unchanged body form and specific gravity across cycles of food availability and sexual reproduction, growth is said to be isometric and b tends to be three. When the general body form changes as the fish grows older then the growth is said to be allometric and b is expected to be greater or less than three (Ricker 1975). Even when growth is isometric there are important seasonal and/or environmental changes expected in b , which relate to such factors as stage of sexual maturity, nutritional adequacy of the diet, and toxicology of the environment. That is, fish of a given length are expected to be heavier if they are well fed, approaching a reproductive event, and not affected by environmental toxins or stress. Since the basic relationship between weight and length of a fish may vary by such factors as species, area, season, nutritional adequacy of the diet, and sustainability of the environment, I believe that one should carefully explore length-weight relationships for a given population rather than assuming the generic equations apply.

The objectives of this study were 1) to determine the best morphometric model correlating weight with various measures of the length and girth of the fish as well as the weights of selected internal organs and 2) to modify the morphometric model into a conservation model using less harmful field measurements.

Methods

Data Collection

Paddlefish were collected¹ in the Mermentau River (29.86° N, 92.85° W), in the old river loop, near the headquarters of Lacassine National Wildlife Refuge (NWR) (Figure 2.1). Lacassine NWR is located in the southwestern portion of Louisiana. The Mermentau River flows into the Gulf of Mexico between Calcasieu Lake and Vermillion Bay on the Chenier Coastal Plain of Texas and Louisiana (Lacoast 2003). The Mermentau River is 71 miles long, and is formed just above the community of Mermentau, LA by junction of Nezipique and des Cannes bayous (Cohen 2000). Bayou Nezipique is considered the spawning ground for Louisiana paddlefish in the Mermentau System (Reed personal communication 2002).

Paddlefish were sampled monthly with the goal of obtaining no more than 15 digestive tracts and gonads per month. Gonads and digestive tracts were taken for the purpose of determining sex and stage of sexual maturity and for conducting gut content analysis (Chapter 3). Fish were collected from March 2002 to February 2003 with two 91m x 3m monofilament gill nets. Each net contained two panels of either 127mm or 154mm bar mesh. Two nets (one of each mesh size) were set perpendicular to the shore in the morning and were lifted hourly to check for and remove paddlefish. The first 15 paddlefish caught were brought aboard and placed in an ice slurry to be euthanized. Once euthanized, paddlefish were measured and weighed before dissection. The measurements included:

¹ Paddlefish collection was conducted under a Louisiana Department of Wildlife and Fisheries, freshwater scientific collection permit (FC-68-02 and FC-28-03) and protocol approved by the Louisiana State University Institutional Animal Care and Use Committee (02-055).

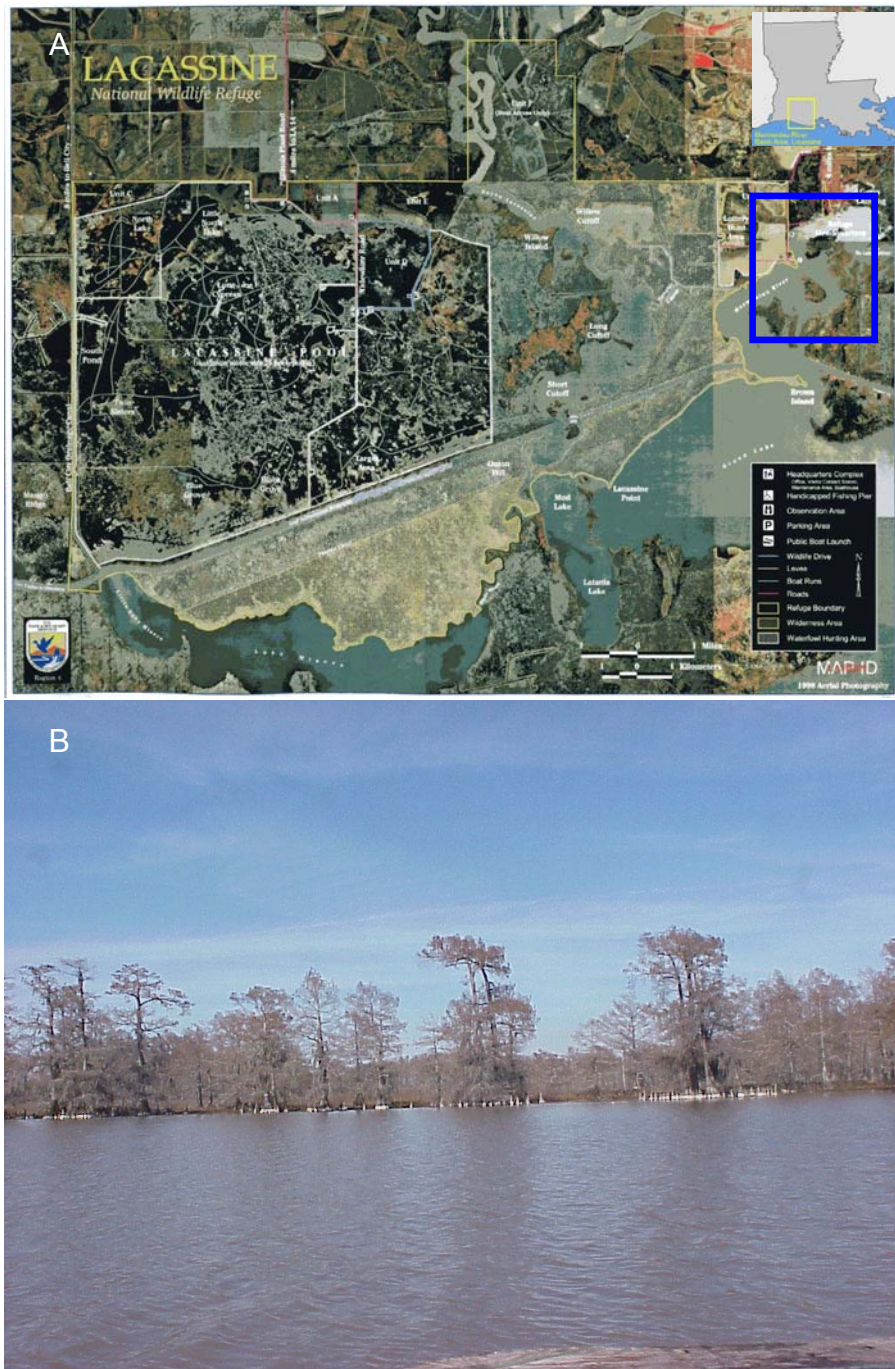


Figure 2.1. (A) Sampling for paddlefish conducted at Lacassine National Wildlife Refuge in the Mermentau River at the old river loop, as indicated by the blue box. Lacassine is located in southwestern Louisiana. (B) Pictorial depiction of the Mermentau River, Louisiana.

- Eye-fork length, EFL, which was measured in millimeters from the anterior orbit of the eye to the fork of the caudal fin (Figure 2.2A);
- Body-cavity length, BCL, which was measured in millimeters from the back of the pectoral fin to the anterior of the vent (Figure 2.2B);
- Girth, G, which was measured in millimeters as the circumference of the paddlefish, approximately one inch behind the pectoral fins, but under the operculum flap (Figure 2.2C);
- Vent girth, VG, which was measured in millimeters as the circumference of the paddlefish in front of the dorsal fin but behind the pelvic fins (Figure 2.2D).

In addition to these measurements of the whole fish three measurements were made of the mouth when it was opened to simulate normal feeding behavior. These mouth measurements were:

- Mouth vertical, MTB, taken from the midline of the dentary bone on lower jaw to the midline of the dentary on the upper jaw (Figure 2.3, line A);
- Mouth horizontal, MSS, taken between the junction of the upper and lower jaw (Figure 2.3, line B);
- Mouth gullet bottom, MGB, taken from the gullet to the midline of the dentary bone on the lower jaw (Figure 2.3, line C).

The fish were then weighed, W, using a field spring scale to the nearest 25 g (Figure 2.2E).

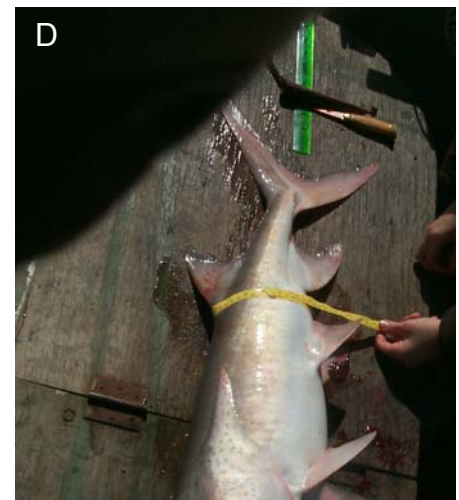


Figure 2.2. Paddlefish body measurements: EFL (A) measured from the anterior orbit of the eye to the fork in the caudal fin; body cavity length (B) measured from the back of the pectoral fin to the anterior of the vent; girth (C) measured as the circumference of the paddlefish, approximately one inch behind the pectoral fins, but under the operculum flap; vent girth (D) measured as the circumference of the paddlefish in front of the dorsal fin but behind the pelvic fins; and weight (E) measured using a field spring scale to the nearest 25 g. In panels A – D, the position of the tape denotes where measurements were made.

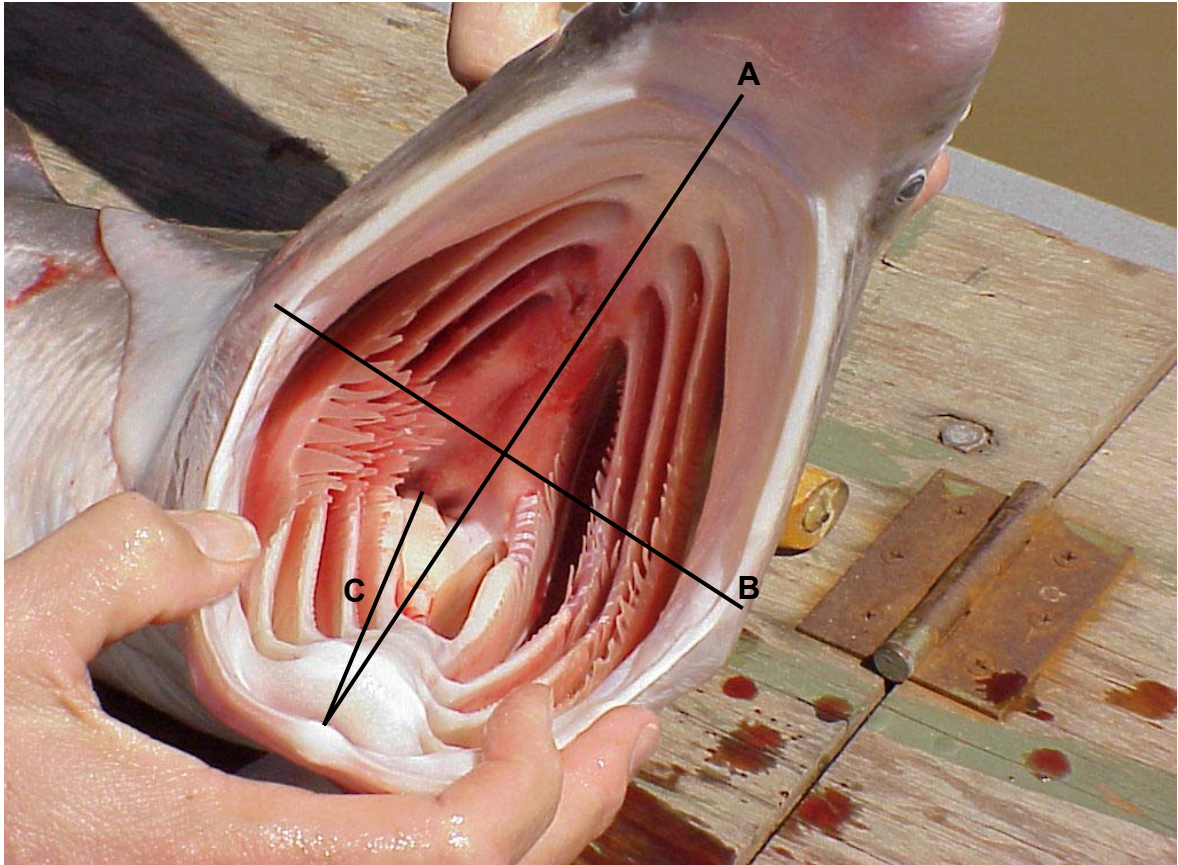


Figure 2.3. The three mouth measurements taken on a paddlefish, showing mouth top to bottom (line A) taken from the midline of the dentary bone on lower jaw to the midline of the dentary on the upper jaw; mouth side to side (line B) taken between the junction of the upper and lower jaw; and mouth gullet bottom (line C) taken from the gullet to the midline of the dentary bone on the lower jaw.

After these measurements were taken the digestive tract and gonads were examined and removed. To reveal the digestive tract and gonads, an incision was made from the vent to the pectoral fin on the fish's left side. The digestive tract was removed by cutting the large intestine at the vent and the esophagus at the mouth. The anterior portion of the digestive tract containing stomach and esophagus was then separated from the posterior portion of the digestive tract and placed in a labeled Ziploc® bag. The posterior portion of the digestive tract including the liver and spleen was placed in another Ziploc bag.

The gonads were examined to determine their stage of sexual maturity using the scale developed by Conte et al. (1988) and were divided into developmental stages: undifferentiated tissue (stage 1); a small ovary with no visible oocytes or testes as a thin strip of tissue (stage 2); a medium size ovary that occasionally could be a "salt and pepper" color or small testes with folds developing (stage 3); and an ovary with large, dark oocytes or testes that were large, lobular, and white (stage 4). The stage of sexual maturity of paddlefish and maturity (sub adult and adult) were verified by Bobby Reed (Louisiana Department of Wildlife and Fisheries). The intact gonads were removed and placed in a Ziploc bag with the rest of the posterior portion of the digestive tract unless the volume of the gonads required a separate bag or bags. Labeled bags were placed in a cooler until return to the laboratory where all of the dissected organs were weighed including: posterior digestive tract (DTW); anterior digestive tract consisting of the stomach and esophagus (SW); large intestine (LIW); and gonad weight (GW). All dissected organs were blotted dry to remove excess water and weighed in a tarred weighing dish on a calibrated scale to

the nearest 0.01 g. The labeled bags containing the still frozen stomach and esophagus were returned to the freezer for further diet analysis (see Chapter 3).

Statistical Analyses

Statistical analysis was performed using SAS version 8.02 software package (SAS Institute Inc. 1999). Size frequency scatter plots were used to examine distributions of weight and EFL. The degree of correlation between these various variables was assessed using Pearson's correlation. The relationship between weight and length was tested for the effect of sex and stage of sexual maturity using analysis of covariance. Forward elimination regression analysis was used to determine the best relationship between the logarithmic natural log transforms of weight and each body measurement. Backward elimination stepwise regression was run to verify that the forward morphometric model was the most appropriate. If both forward and backward procedures agreed, the result was accepted as the final morphometric model. I then looked at the morphometric model with the intent of removing parameters that I thought would harm the fish in the field (such as the mouth measurements) and included less intrusive measurements that I felt would increase the overall reliability of the model. This model was run using the regression procedure to result in a conservation model.

Results

One hundred thirty-one paddlefish were sampled from the Mermentau River between March 27, 2002 and February 19, 2003. Of the 131 paddlefish collected, 66 were female (41 mature) and 65 were male (41 mature). Paddlefish ranged from 281-977 mm EFL (mean, 758; SE, 89) and from 1,025-11,675 g (mean, 6,267; SE,

1,900). There was a positively skewed distribution of fish length (EFL) (Figure 2.4A), favoring larger size classes and a fairly even distribution of fish based on weight (W) (Figure 2.4B). Immature fish ranged from 281 mm to 884 mm with a mean of 712 mm. Mature fish ranged from 615 mm to 977 mm with a mean of 785mm. Immature fish had weights that ranged from 3350 g to 8850 g with a mean of 5410 g. Mature fish ranged from 3150 g to 11,675 g with a mean of 6780 g.

Most morphometric measurements were significantly correlated (Table 2.1). All non-significant correlated measurements involved weights within the body cavity. The following parameters had the strongest correlation with weight: EFL (0.87), G (0.92), VG (0.87), and BCL (0.90). There were no significant relationships between GW and either SW, DTW or LIW.

Weight and EFL were related by a power function that described the relationship for both mature and immature fish of either sex (Figure 2.5). Using the mixed procedure in SAS, I tested for the effect of sex and stage of sexual maturity on the relationship between weight and EFL and found that there was no effect for either, $p=0.2963$ and $p=0.8852$. One point was identified as an outlier. This was an immature male with a weight of 3350 g and an EFL of 281 mm, which was not used in further analyses. I investigated this suspect EFL point using influential diagnostics in the regression procedure in SAS. When looking at the influential statistics (Freund and Wilson 1997; Elliot 2000) of DFBetas and Rstudent, logEFL had a value of -15.96 for DFBetas when this value should not have exceeded 0.17 and had a

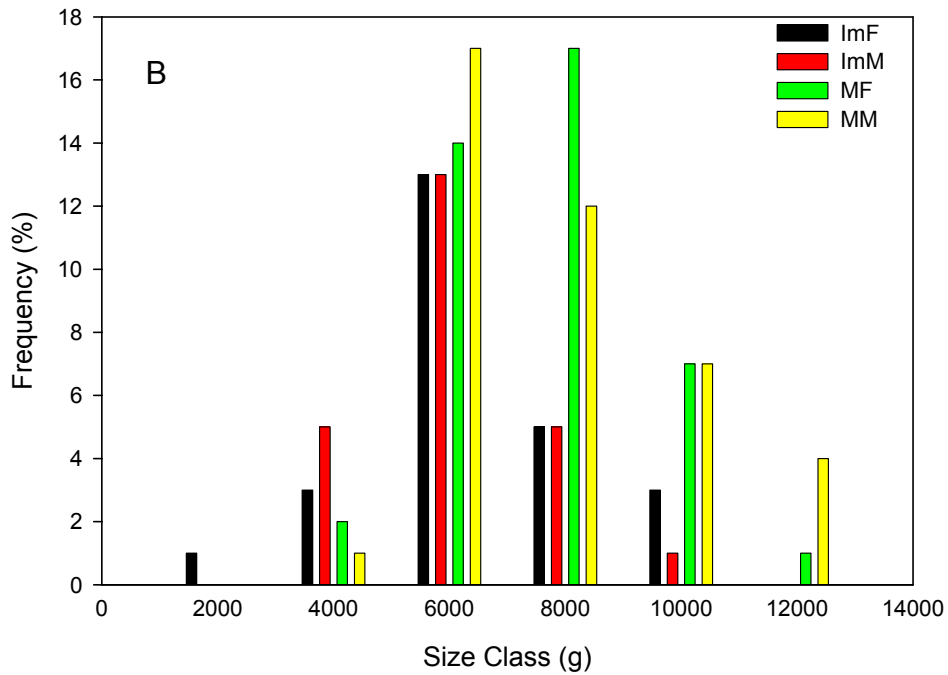
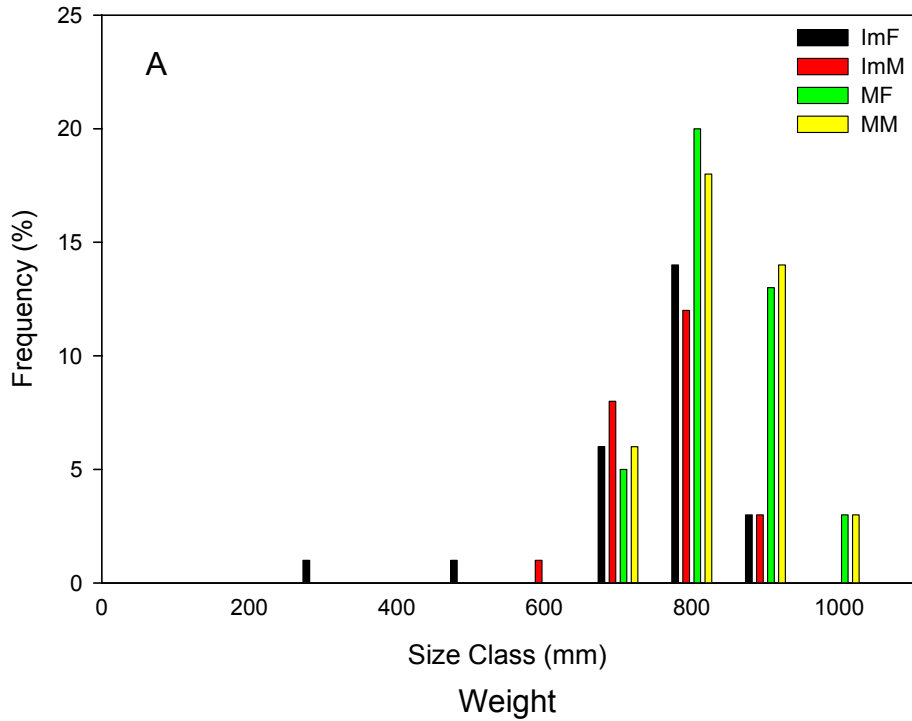


Figure 2.4. Frequency distributions for EFL (A) and weight (B) of immature male and female paddlefish and of mature male and female paddlefish collected in the Mermentau River, Louisiana. Size class bins consist of fish sizes up to the size used to label that bin; for example, the bin 400 mm includes fish from 301 mm to 400 mm.

Table 2.1. Pearson correlation coefficients for all morphometric measurements for paddlefish collected in the Mermentau River, Louisiana. Within each cell correlation coefficients are listed as the first number, significance level is listed as the second number and the sample size is listed as the third number. EFL=eye-fork length, W=weight, G=girth, VG= vent girth, BCL= body-cavity length, MSS= mouth side to side, MTB = mouth top to bottom, GW= gonad weight, SW= stomach weight, DTW= digestive tract weight, and LIW= large intestine weight. Table continued on next page.

	EFL	W	G	VG	BCL	MSS	MTB	MGB	GW	SW	DTW	LIW
EFL	1 . 131	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
W	0.870 <.0001 131	1 . 131	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
G	0.817 <.0001 131	0.924 <.0001 131	1 . 131	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
VG	0.767 <.0001 121	0.868 <.0001 121	0.904 <.0001 121	1 . 121	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
BCL	0.854 <.0001 121	0.897 <.0001 121	0.836 <.0001 121	0.768 . 121	1 . 121	- - -	- - -	- - -	- - -	- - -	- - -	- - -
MSS	0.742 <.0001 131	0.75 <.0001 131	0.744 <.0001 131	0.679 <.0001 121	0.733 <.0001 121	1 . 131	- - -	- - -	- - -	- - -	- - -	- - -
MTB	0.546 <.0001 129	0.500 <.0001 129	0.511 <.0001 129	0.516 <.0001 119	0.357 <.0001 119	0.604 <.0001 129	1 . 129	- - -	- - -	- - -	- - -	- - -
MGB	0.801 <.0001 121	0.816 <.0001 121	0.754 <.0001 121	0.709 <.0001 121	0.824 <.0001 121	0.779 <.0001 121	0.588 <.0001 119	1 . 121	- - -	- - -	- - -	- - -

Table 2.1 cont'd

	EFL	W	G	VG	BCL	MSS	MTB	MGB	GW	SW	DTW	LIW
GW	0.375	0.496	0.522	0.397	0.567	0.355	0.204	0.403	1			
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0208	<.0001	.	-	-	-
	129	129	129	119	119	129	127	119	129			
SW	0.192	0.222	0.375	0.311	0.233	0.354	0.123	0.237	-0.029	1		
	0.029	0.0114	<.0001	0.0006	0.0105	<.0001	0.1668	0.0094	0.7412	.	-	-
	129	129	129	119	119	129	127	119	129	129		
DTW	0.272	0.369	0.537	0.481	0.290	0.365	0.217	0.299	-0.016	0.847	1	
	0.0018	<.0001	<.0001	<.0001	0.0014	<.0001	0.0142	0.0009	0.8542	<.0001	.	-
	129	129	129	119	119	129	127	119	129	129	129	
LIW	0.169	0.239	0.369	0.283	0.144	0.275	0.286	0.216	-0.105	0.748	0.882	1
	0.0859	0.0144	0.0001	0.0035	0.1444	0.0047	0.0032	0.0275	0.2873	<.0001	<.0001	.
	104	104	104	104	104	104	104	104	104	104	104	104

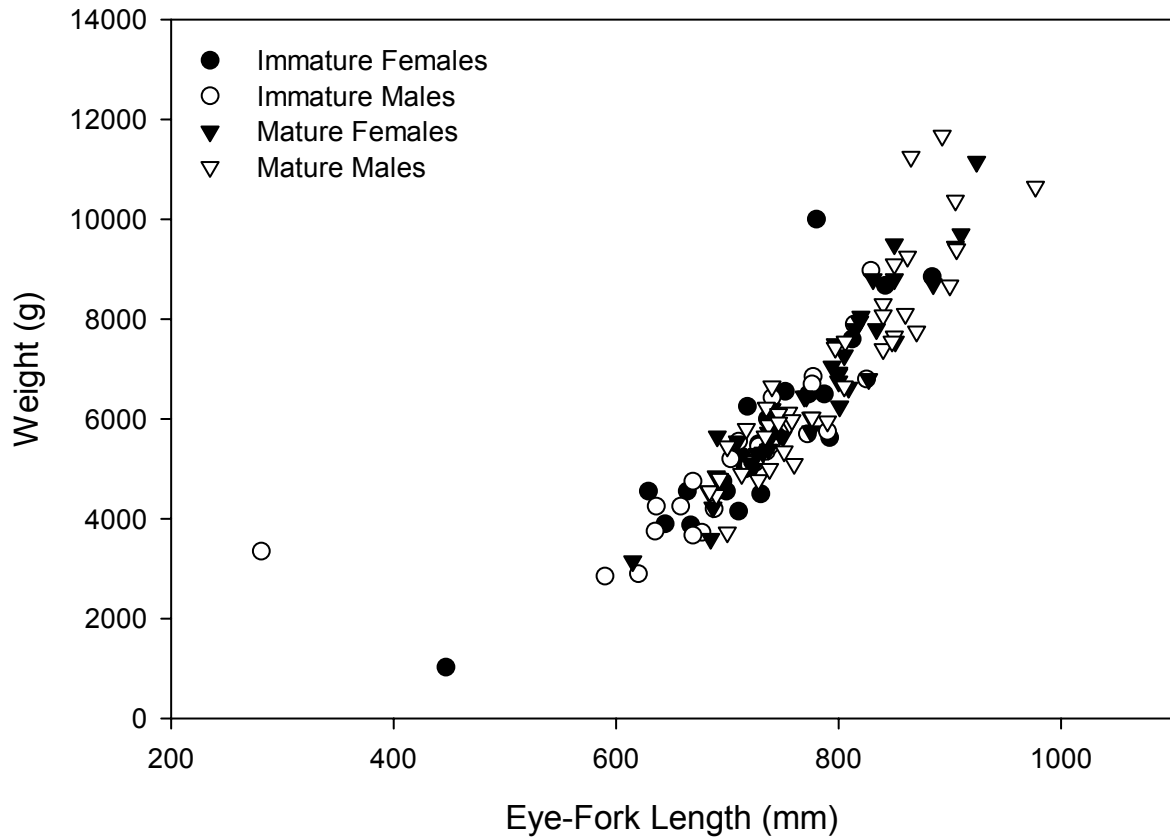


Figure 2.5. Weight eye-fork length relationship for immature and mature male and female paddlefish collected in the Mermentau River, Louisiana.

high $R_{student}$ (which contains the deleted standardized residuals) value of 5.88 when this value should not have exceeded two. Therefore, the resulting length weight relationship ($R^2 = 0.89$) was:

$$\log W = -10.51 + 2.90(\log EFL). \quad (3)$$

A curvilinear trend was observed with G and VG. A quadratic function described the relationship between girth and weight (Figure 2.6A), while vent girth and weight were not related via a quadratic function ($p = 0.0517$).

A linear trend was observed with BCL and weight (Figure 2.6C) and MSS and weight (Figure 2.6D). Weight and MGB showed random scattering with no apparent pattern (Figure 2.6E). There was a complex and variable relationship between weight and GW with most of the points concentrated around GW less than 500 g (Figure 2.6F). However, for fish greater than approximately 6000 g, there was a scatter of GW in excess of 500 g. There was a scattered, positive relationship between weight and DTW with a lot of outward spread, that is, as the fish got heavier the spread for DTW increased (Figure 2.6G).

The morphometric model (equation 4) had a coefficient of determination of 0.97:

$$\log W = 10.10 + 1.52 (\log EFL) + 1.21 (\log G) + 0.24 (\log VG). \quad (4)$$

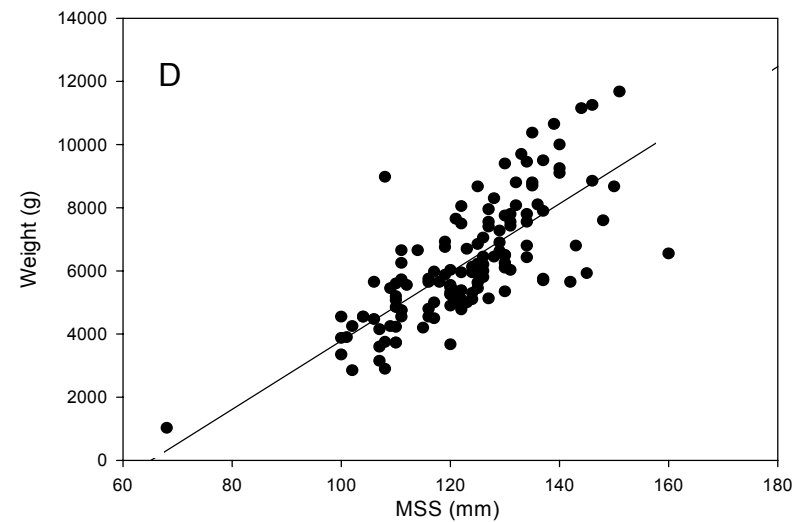
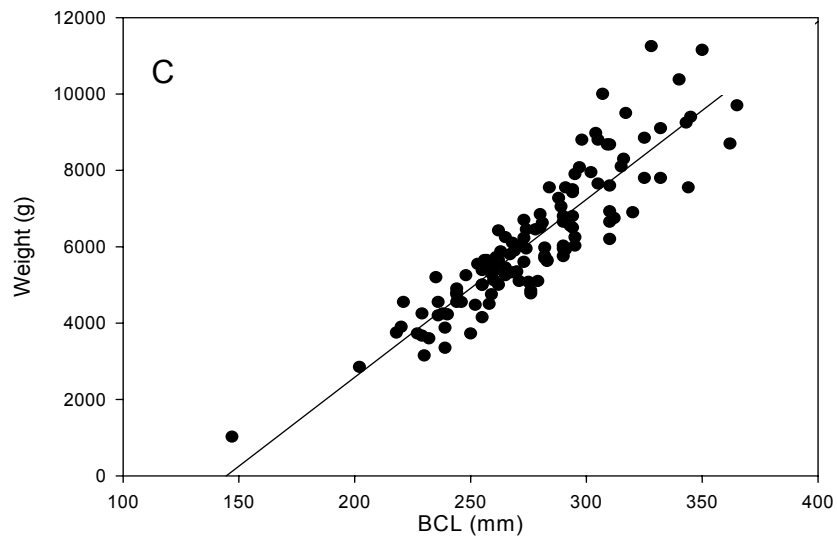
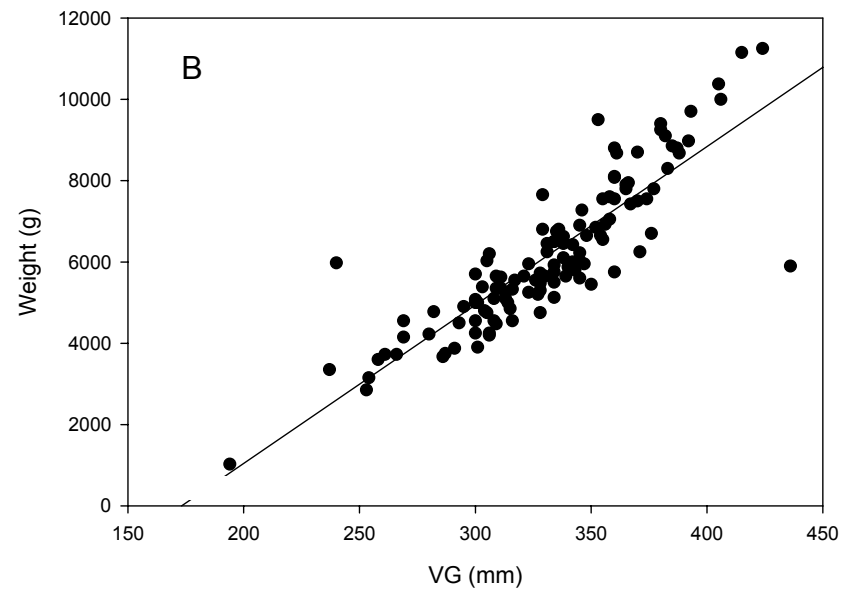
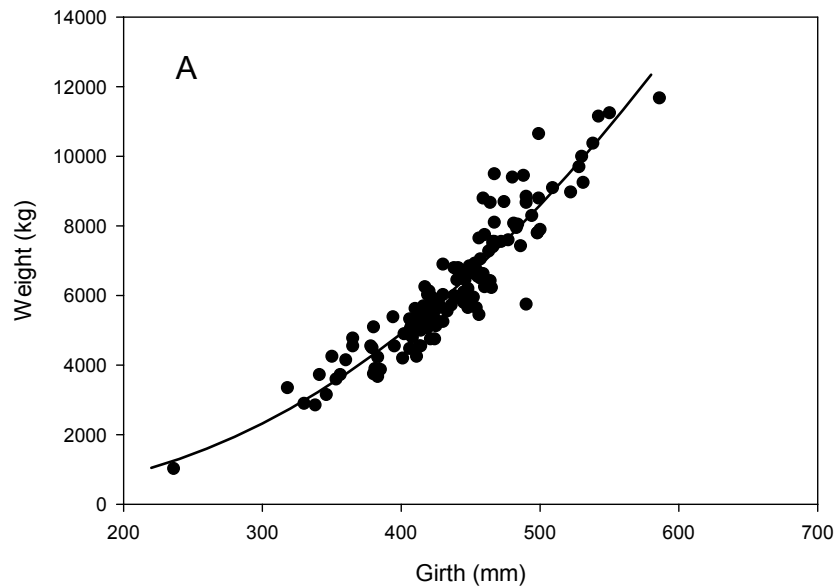


Figure 2.6. Graphical representation for selected morphometric measurements for paddlefish collected in the Mermentau River, Louisiana. (A) Weight versus girth, G; (B) vent girth, VG; (C) body cavity length, BCL; (D) mouth side to side, MSS; (E) mouth gullet bottom, MGB; (F) gonad weight, GW; and (G) digestive tract weight, DTW. Curved line in panel (A) represent the solution to a quadratic regression, while straight lines in panels B through D represent the solutions to linear regressions.

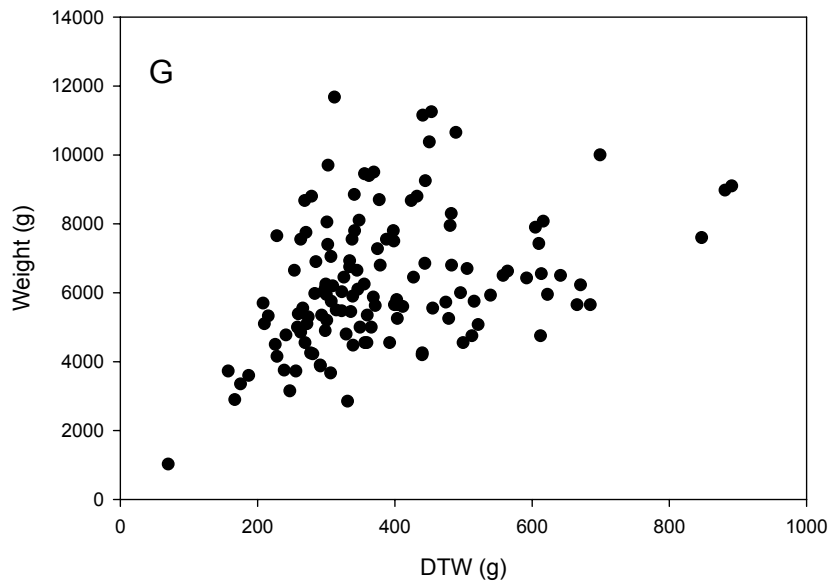
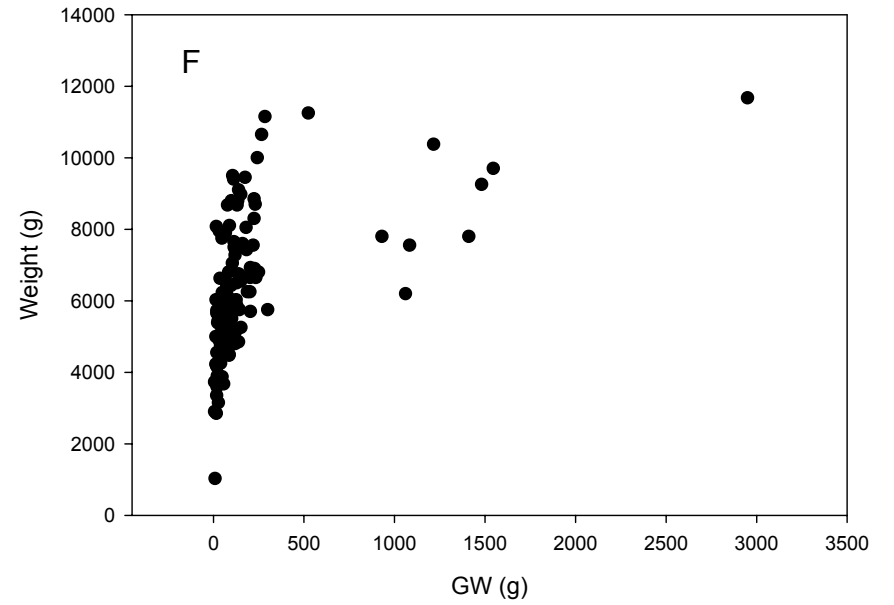
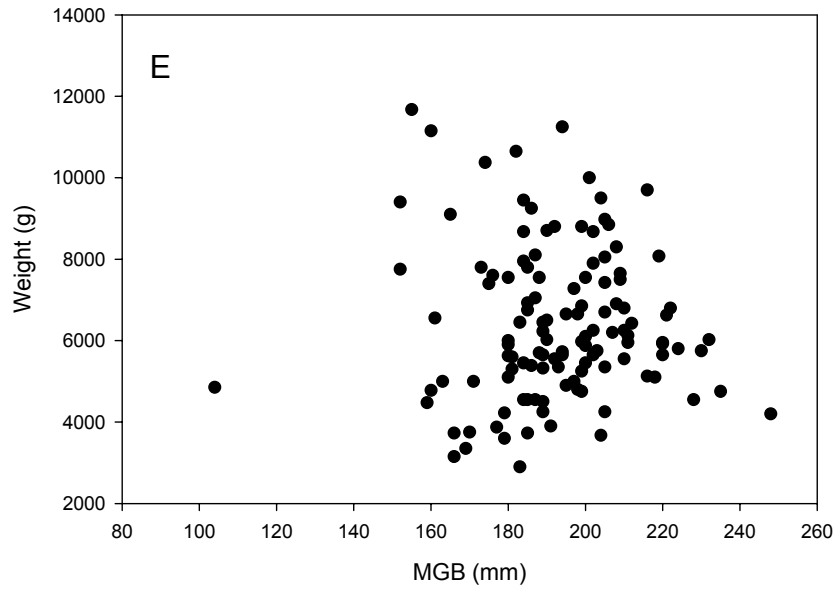


Figure 2.6 continued.

I then developed a conservation model by removing any parameters that I felt would adversely affect the fish while it was being measured in the field. Therefore, I removed GW, DTW, MSS, MTB, and MGB. This model (equation 5) had a coefficient of determination of 0.97. The preliminary conservation model was then tested using the backward stepwise regression and resulted in the same three parameter model. The resulting preliminary conservation model was the same as Eq. 4. However, in the final conservation model I included BCL as a precautionary measure to discount the impact of potential errors in obtaining field measurements. The resulting four-parameter model is given below in equation 5:

$$\log W = -9.82 + 1.15 (\log G) + 1.39 (\log EFL) + 0.25 (\log VG) + 0.15 (\log BCL). \quad (5)$$

Discussion

Morphometric analysis revealed that paddlefish sampled in the Mermentau River, Louisiana exhibited no effect of sex and stage of maturity on the relationship between weight and EFL.

Length and weight data provide statistics that are cornerstones in the foundation of fishery research and management (Anderson and Neumann 1996). These measurements allow biologists to estimate growth, standing crop, and production not only in natural waters but also in fish hatcheries. Length measurements can be used to evaluate length frequencies or size classes of fish, as in recreational fishery size limits. This data allows biologists to assess fish populations and monitor them over time with different management plans.

Weight measurements can be used to express harvest or standing stocks. Weight at age and annual weight increments are statistics that describe the growth process (Anderson and Neumann 1996). These increments can evaluate how fish gain in value to a fishery.

Weighing a fish in the field (*in situ*) is not as easy as measuring the length of the fish. The accuracy associated with weight measurements is determined by the accuracy and precision of the weighing device, the amount of moisture on fish, and changes in the fish caused by death or preservation (Anderson and Neumann 1996). Weighing of a fish in the field calls for extra steps to ensure accuracy. These steps include blotting water off the fish, making sure the scale is calibrated, obtaining the appropriate scale, and sensitivity of the scale to motion, wind and the fish. Gutreuter and Krzoska (1994) examined the precision of *in situ* weight measurements and recommended elimination of routine *in situ* weighing from fish monitoring programs unless a specific, scientifically justified need for weight data was needed. The present study highlights the potential impact of any erroneous field measurements (i.e. length and weight) and highlights the importance of taking several different morphometric measurements so that a better explanation of weight can be obtained from regression models.

I believe that measurements used to develop the conservation model for paddlefish will prove useful for stock assessment work. This study was performed based on the MICRA paddlefish studies and I would recommend that these results be used to address the populations of paddlefish stocks throughout the Mississippi

River drainage area. This information may help in growth studies as well as restocking programs.

Length weight relationships were compared for paddlefish collected in this study to paddlefish in other published studies throughout their distribution range to see if a difference was seen in reservoir/lake and river paddlefish. Mermentau River fish were first compared to other populations of Louisiana fish (Atchafalaya River, Henderson Lake and Lake Pontchartrain) reported from Reed et al. (1992). Regressions given by Reed et al. were solved for the ranges of fish used by these authors in developing each of their equations. My fish were very similar to Reed's Atchafalaya River fish but were different from Reed's Lake Henderson and Lake Pontchartrain fish. The Lake Henderson fish were predicted to be heavier at any given eye-fork length than the Mermentau or Atchafalaya River fish (Figure 2.7). Lake Pontchartrain fish initially followed the same relationship as the Mermentau and Atchafalaya River fish but began to exhibit heavier weights than the river fish when eye-fork lengths were greater than about 800 mm. In addition, much larger and heavier fish were reported for Lake Pontchartrain than for any of the other Louisiana systems.

Length weight relationships from these Louisiana populations were also compared to other systems in the paddlefish range using regressions from Brown and Murphy (1993) and Hoximeier and DeVries (1997) (sexes combined data). Regressions given by Hoximeier and DeVries (1997) were solved for their fish ranges. However, since Brown and Murphy did not list the size range of fish used, I solved their regressions for the mean length of the fish and used ± 300 mm as this

Louisiana Paddlefish

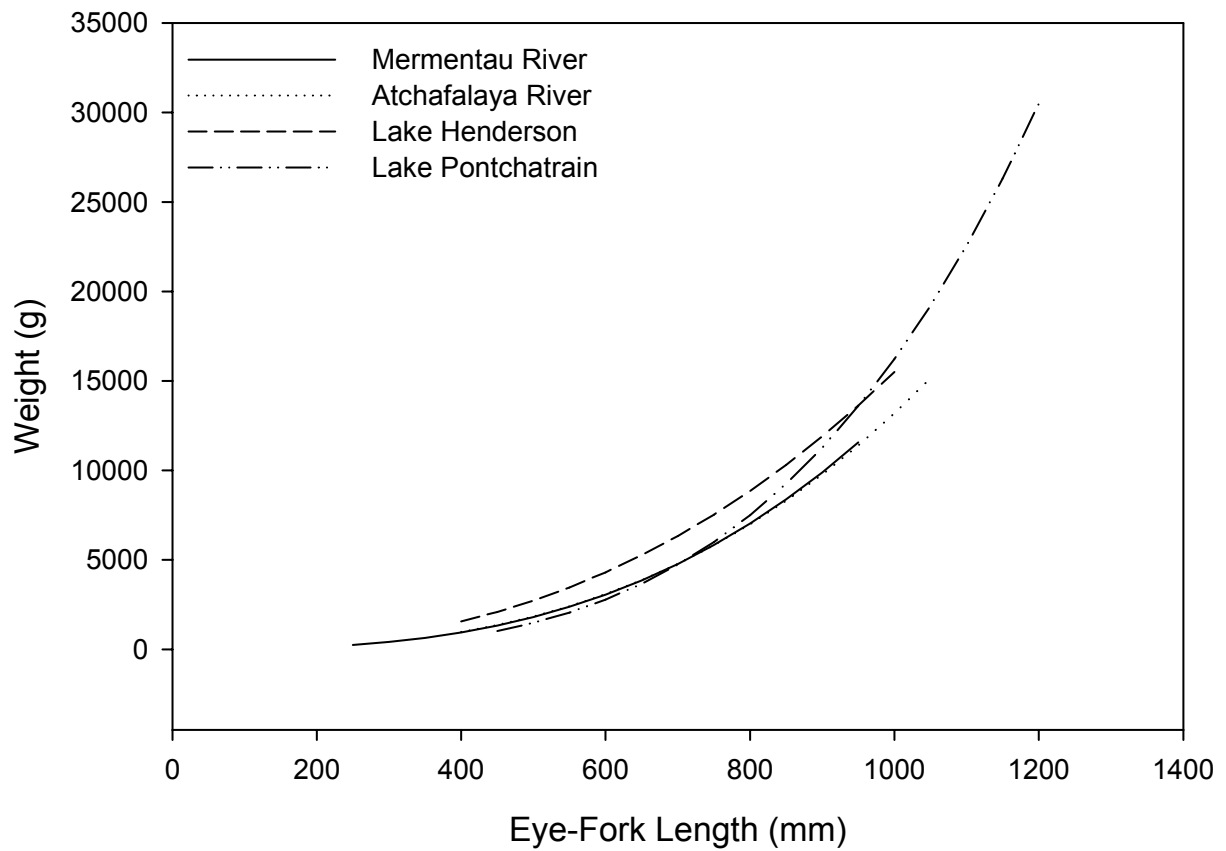


Figure 2.7. Weight eye-fork length relationship of Louisiana paddlefish (sexes combined) collected in the Mermentau River compared to weight eye-fork length relationships of paddlefish from the Atchafalaya River, Lake Henderson and Lake Pontchartrain (Reed et al. 1992). Regressions were solved for the ranges of fish used in developing each equation.

approximated the ranges used in the other paddlefish studies. As a group, the reservoir fish tended to be heavier than river fish for eye-fork lengths above 800 mm with one major exception (Figure 2.8). That exception is the Lower Alabama River, which showed much heavier weights for a given eye-fork length than the rest of the river areas and were in the high range of the reservoir systems above 800 mm. The Louisiana Rivers reflected the low end of length weight relationships.

Since hydraulic transport processes tend to disperse plankton (e.g. Hembre and Megard 2003), one might expect less turbid waters in reservoirs/lakes than in rivers, therefore, allowing for higher concentrations of patchy plankton available for paddlefish to feed upon. Based upon the results presented in Figure 2.8, this interpretation supports the hypothesis that river fish should be lighter at a given eye-fork length than reservoir/lake fish because food is generally less abundant in concentrated patches. Since Louisiana fish are consistently within the lower range of all the fish populations examined in Figure 2.8, I suggest the reason may be due to a combination of our higher suspended sediment loads and temperatures of our waters in general. The former would mechanically decrease the relative abundance of living organic matter in the water column and the later would increase the metabolic rate.

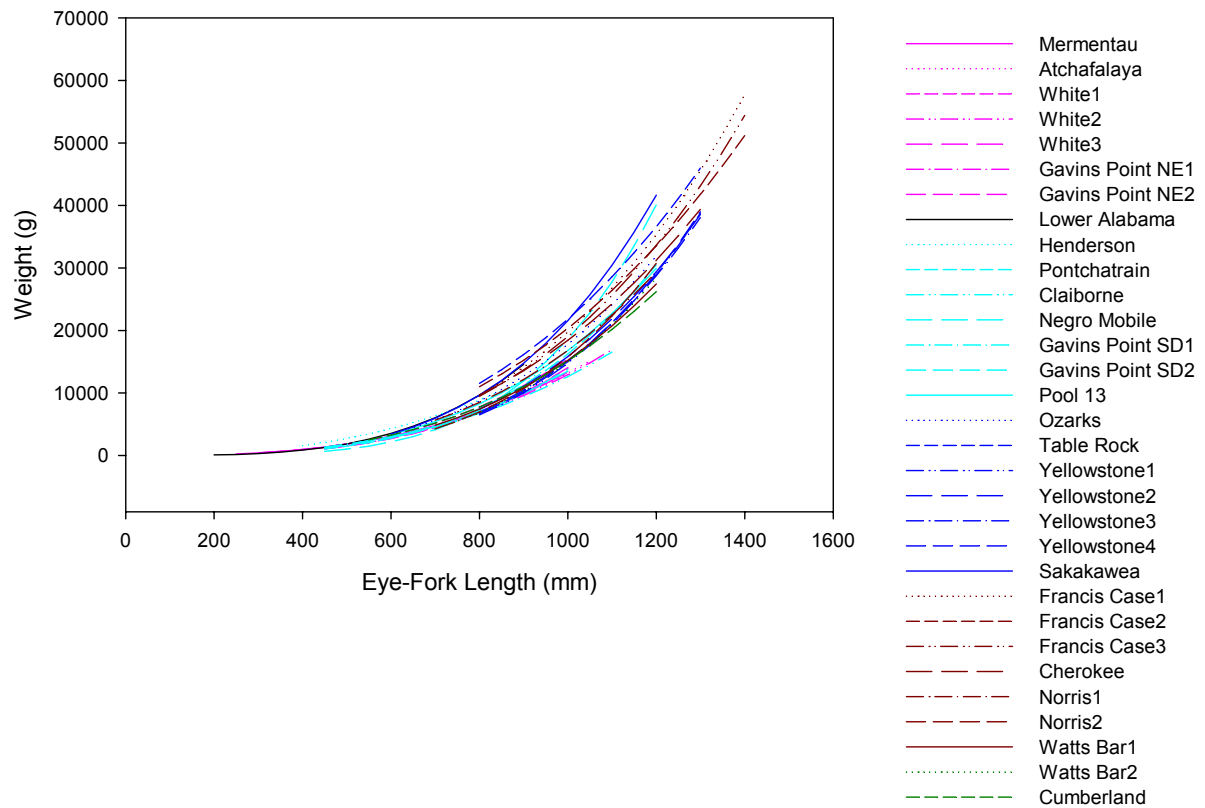


Figure 2.8. Weight eye-fork length relationships comparing paddlefish from 31 areas in the United States. With the exception of Brown and Murphy's (1993) study, each regression was solved for the range of fish used in developing each equation. For Brown and Murphy's study, regressions were developed from the mean length of the fish \pm 300 mm. Areas included: Mermentau River, Louisiana; Atchafalaya River, Louisiana; White River, Arkansas (sampled three years); Gavins Point Dam, Nebraska (sampled two years); Lower Alabama River, Alabama; Henderson Lake, Louisiana; Lake Pontchartrain, Louisiana; Lake Claiborne, Alabama; Lake Negro, Alabama; Gavins Point Dam, South Dakota (sampled two years); Pool 13 reservoir, Iowa; Lake Ozarks, Missouri; Table Rock Lake, Missouri; Yellowstone River, Montana (sampled four years); Sakakawea reservoir, North Dakota; Francis Case reservoir, South Dakota (sampled three years); Cherokee reservoir, Tennessee; Norris reservoir, Tennessee (sampled two years); Watts Bar reservoir, Tennessee (sampled 2 years); Lake Cumberland, Kentucky. River fish are denoted in pink, except the Lower Alabama River, which is in black. Reservoir/lake fish are denoted by all the other colors. Louisiana data (excluding the Mermentau River) were taken from Reed et al. (1992). Lake Cumberland, KY data were taken from Hoximeier and DeVries (1997).

CHAPTER 3
**FEEDING ECOLOGY OF PADDLEFISH IN THE MERMENTAU RIVER,
LOUISIANA**

Introduction

Early biologists described adult paddlefish as bottom feeders that ate minute vegetable and animal organisms found by stirring up the mud and vegetation with their spatulate snout (Alexander 1914, Stockard 1907). This thought was later dismissed by Eddy and Simer (1929) who discovered paddlefish were planktivorous feeders. Based upon her review of the literature, Gerking (1994) described paddlefish as ram or tow-net filterers who swim with their mouth agape and opercles flaring. In her discussion of ram filtration (p. 172) she described how gill rakers in fish presumably behave as a sieve to catch plankton. As reviewed below, most contemporary publications on paddlefish report the diet as consisting of crustacean zooplankton (Rosen and Hales 1981, Hoxmeier and DeVries 1997, Hageman et al. 1986), while a few have noted other items being found in the stomachs. For example, Fritz (1966) reported fish remains being found in the diet.

The feeding of young-of-the-year paddlefish has been described in three papers. Ruelle and Hudson (1977) found young of the year paddlefish (less than 200 mm in length) in Lewis and Clark Lake, on the Nebraska and South Dakota border, selected for the largest available zooplankter (*Daphnia pulex*). Their diet was composed of crustacean zooplankton (76%), six species of aquatic insects (21%), and clover leafhoppers, a terrestrial insect (3%). Ruelle and Hudson summarized their findings by taxonomic classification and size in terms of average abundance and frequency of occurrence. Michaletz et al. (1982) found that

young-of-the-year paddlefish gradually switched from particulate to filter feeders as they reached 120 mm in length and speculate that the switch to filter feeding supported faster growth rates. Filter feeding was not dependent upon the full development of the gill rakers and resulted in the ingestion of smaller sized prey items than was evident during the particulate feeding stage. Kozfkay and Scarnecchia (2002) found that age-0 paddlefish selectively fed and disproportionately selected larger prey organisms. Moreover age-0 paddlefish avoided cyclopoid copepods and large cladocerans and fed on small cladocerans less than or equal to their availability, indicating avoidance or random feeding.

Kozfkay and Scarnecchia appear to be the only authors who describe the feeding ecology of Age-1 paddlefish. They found that Age-1 paddlefish avoided small cladocerans and cyclopoid copepods. Their research showed that juvenile paddlefish were able to acquire large numbers of preferred prey, and may delay their switch to filter feeding until they reach a body length of 300 mm.

There have been four publications on the feeding of adult paddlefish. Rosen (1976) and Rosen and Hales (1981) conducted the most comprehensive study, which found that adult paddlefish in the Missouri River fed “almost entirely on crustacean zooplankton” (Rosen and Hales 1981). They classified paddlefish as indiscriminate filter feeders on particles greater than 0.20-0.25 mm in length and 0.10-0.12 mm in width. Higher rates of ingestion were in the spring and fall with a cessation of feeding in late June to early September.

Hoxmeier and DeVries (1997) and Hageman et al. (1986) also found that adult paddlefish fed predominately on crustacean zooplankton in the lower Alabama

River and Lake Cumberland, Kentucky, respectively. Stomach fullness and crustacean composition of the diet varied by season and habitat (Hoxmeier and DeVries 1997), but they were unable to identify specific season and area patterns in these parameters. Hageman noted that midges were common in September-October and May-June, green 'plant matter' was common in October, and stomach contents were reduced in February.

Nothing is recorded on the feeding ecology of adult paddlefish in Louisiana other than the early reports of Alexander (1914) and Tulian (1916). The objectives of this study were to examine the feeding habits of sub adult and adult paddlefish in the Mermentau River. Specifically I was interested in: 1) the identity and size distribution of the prey items by functional groups; and 2) the effect of season and stage of sexual maturity on the composition of the diet.

In addition, as my research progressed, questions of selectivity arose and I undertook a limited investigation of the relative size of crustacean zooplankton found in the stomach of my captured paddlefish and those on the surface water adjacent to my sampling site.

Methods

The study site and field procedures have been described in Chapter 2 of this thesis. Fish were absent in October apparently due to low oxygen conditions believed to be the result of Hurricane Lily and tropical storm Isidore hitting Louisiana in late September and early October 2002.

Stomach Content Removal

Prior to stomach content analyses, I took cross sections of one of the apparently full frozen stomachs at the anterior, middle, and posterior positions to determine if there were different stages of digestion within the stomach. I removed the gut contents from each of these cross sections and examined the contents of each section separately with a dissecting microscope for indications that the contents or their condition differed by region. This gross stereoscopic examination failed to reveal any partitioning of food items by region. Rather, there appeared to be a fairly uniform mix of largely crustacean zooplankton in a fairly uniform stage of mechanical disruption. Moreover, the contents were tightly compact suggesting that ingestion had not been accompanied by a large intake of water.

Therefore, it was decided to remove the entire frozen content of each stomach and obtain the weight of the frozen mass as an index of the maximum gut content at the time of capture. Each frozen stomach was split along the outside starting from the esophagus and ending at the connection to the large intestines. The skin was folded back, and the frozen contents everted onto a tarred weighing dish. Any stomach contents that remained were removed and placed with the rest of the frozen contents. Stomach contents were weighed to the nearest 0.01g and preserved in 70% ethanol until subsequent dietary analysis.

Diet Analysis

Displacement volumes were computed for a random sample of (n=57) stomachs as a back up to the weighing of the frozen stomach contents. These values were to be compared to the weights of the stomach contents. To obtain the

displacement volume, I followed the procedure outlined in Postel et. al. (2000), however, I used sieves in place of a filtration apparatus.

The relationship between displacement volume and stomach contents was examined to determine the appropriate numerical function describing the two variables. I found through the regression analyses presented in the results that there was a general agreement between these two indices of gut contents. I therefore discontinued the measurements of displacement volume when I saw that they did not add additional information to the emerging trends I was finding in the seasonality of ingestion.

Prey Identity Analysis

Stomach contents were analyzed using the procedures outlined in Postel et al. (2000). Samples were subsampled using a Hensen-Stempell pipette following each displacement volume. Each subsample was placed in a Bogorov tray and examined using a dissecting microscope. Organisms were identified down to the lowest taxonomic group. Copepods and cladocerans were the major taxonomic groups found and were counted until 100 had been tallied. Identification of invertebrates was obtained from Pennak (1978) fresh-water invertebrates of the United States. The percent composition by number (%N) and percent occurrence (% O) were estimated for prey identified to genus. As organisms were counted they were picked out and placed in separate labeled vials. Diatoms (filamentous algae) were not included in the analysis because they were not enumerated.

Length frequency measurements of invertebrate prey items were taken from fish collected during November 26, January and February to compare with

corresponding zooplankton net tows. Previously counted prey items of each taxonomic group were poured into a petri dish. The contents of the dish were imaged using a digital camera/microscopy system (Pixera VCS 1.2.3) and measured using an image processing software program (NIH Image 1.62) (Keenan 2003).

Zooplankton Sampling

Zooplankton tows were taken in November 2002 and January and February 2003. A one-half meter mouth, 335 μ m mesh plankton net with a 333 μ m cod-end equipped with a flow meter (General Oceanics Model 2030) was used to sample the planktonic community. Three replicate 10-minute tows were taken from the boat during each trip, each following the collection of fish from the gill nets. The tows were taken at and just below the surface of the Mermentau River. Plankton samples were preserved in 70% ethanol.

All net tows were examined through silhouette photography (Ortner et. al. 1979; Davis and Wiebe 1985). Each net tow was poured onto a piece of labeled photographic film (Kodak, fine grain positive, 8 x 10in.). A strobe light was then flashed to expose the film, which was developed using Kodak developer for one minute followed by standard stop bath and fixative procedures.

Silhouette photographs were digitized as tagged image file format (TIFF) files at 1200 pix/inch resolution and lengths of imaged organisms were measured in a Matlab program (Digitizer 1.0) (Little and Copley 2003). Silhouettes were uploaded into Matlab digitizer and a grid (22 x 18 cells) was superimposed on each image. Thirty-two cells were then randomly selected for counting. In each cell, organisms were measured with the goal of counting 100 total individuals of the major groups.

The major groups included copepods and cladocerans. Other taxonomic groups were also counted; their abundances were typically much lower than copepods and cladocerans. These less abundant taxa were ostracods, insects, and a miscellaneous group that included organisms such as arachnids and phytoplankton. Once all measuring was complete for a silhouette, the lengths were saved in a text file for size selectivity analysis.

Size Selectivity

When my study first began, I had intended to focus on the gut contents of paddlefish and compare my results with what was known about the plankton composition of the Mermentau River system. As my study progressed, it became apparent that there were no published studies on plankton in the Mermentau River or adjacent, comparable river systems. I therefore undertook a limited analysis of the plankton at my study site for a preliminary examination of selectivity patterns, under the assumption that the plankton samples obtained would be representative of the plankton community upon which my paddlefish were feeding.

Size selectivity was examined during the last month of the fall and the last two months of the winter season (November, January and February). Size frequency distributions from net tows were compared to the size frequency distributions from the fish stomachs for copepods and cladocerans. The abundances of insects, ostracods, amphipods and decapods in stomachs or net tows samples were too low to evaluate size selectivity. Diatoms were not included because they were not enumerated. Prey categories were placed in 0.1 mm size classes, from 0.1 to 1.8.

The three months were pooled together to make a stronger evaluation of the size selectivity of paddlefish.

As described in Keenan 2002, Chesson's alpha (Chesson 1983 in Keenan 2002) was calculated to evaluate prey size selectivity:

$$\alpha_i = \frac{(r_i / p_i)}{\sum r_j / p_j} \text{ for } j = 1 \text{ to } m \quad (6)$$

where α_i is the selectivity for the i^{th} size class for an individual paddlefish; r_i is the numerical proportion of the i^{th} size class in an individual paddlefish stomach; p_i is the numerical proportion of the i^{th} size class in the environment; and m is the number of size classes observed in the net tows.

Chesson's alpha values were calculated for each size class for copepods and cladocerans for each paddlefish caught during November (n=4), January (n=3) and February (n=7). Alpha values for each month were calculated independently from each other and thus could be pooled for analysis (Chesson 1983 in Keenan 2002). Positive selection occurred when $\alpha_i > 1/m$ and negative selection occurred when $\alpha_i < 1/m$. T-tests were run to determine significance of the selection.

Statistical Analysis of Diet

Statistical analyses were performed using the software package PRIMER (Clarke and Warwick 2001) to determine if paddlefish had similar diets among seasons and stages of sexual maturity of the gonads and to determine what taxonomic groups contributed to the similarities or differences in the diet. Paddlefish

were divided into two categories, season: spring (March-May), summer (June-August), fall (September-November), and winter (December-February) and stage of sexual maturity of the gonads (as described in Chapter 2 methods). These categories were analyzed by % N of each prey functional groups excluding nematodes and diatoms, as nematodes were parasitic and diatoms were not counted. Bray-Curtis similarity coefficients were constructed to determine similarities in %N among the seasons and stages of sexual maturity. Multi-dimensional scaling (MDS) was performed next, using the Bray-Curtis similarity coefficients, to determine ordination similarities. Analysis of similarities (ANOSIM) was then used to determine significant differences among the seasons and stages. R-statistic values were interpreted as follows: $R \geq 0.75$ indicated differences between groups with no overlap; R less than 0.75 but greater than or equal to 0.5 indicated some differences between groups but some overlap; and $R < 0.5$ indicated the groups were barely different or not separate. Similarity percentages (SIMPER) were used to define the contribution certain prey categories made to the overall similarity or dissimilarity. Finally, a stepwise approach (BVSTEP) was used to assess which prey categories were influential for the observed patterns.

Results

One hundred twenty nine paddlefish stomachs were examined in which 21 were empty, 13 contained only parasitic nematodes, 45 contained food items only and 50 had food and parasitic nematodes. Of the 95 paddlefish with food in their stomachs, 12 paddlefish were in stage one of maturity of the gonads, 47 were in

stage two of maturity of the gonads, 36 were in stage three of maturity of the gonads, and one was in stage four of maturity of the gonads. Twenty-six paddlefish were caught in the spring, 32 in the summer, 22 in the fall, and 15 in the winter. At no point did I feel paddlefish were regurgitating because when food contents were found in the esophagus it was due to a full stomach and at no point did an empty stomach have a distended stomach wall.

Diet Analysis

The ratio of stomach weight (SW) to fish weight (W) was used to derive an Index of fullness (I_f):

$$I_f = SW / W \quad (7)$$

which is compared by date of capture in Figure 3.1. In March, as the spawning season was ending, a low I_f gradually increased towards the end of spring through the beginning of the summer months. An initial peak in feeding was seen from May through July. The end of the summer showed a decline in feeding as the I_f values approached the fall months. After October, a second peak was seen in feeding during the winter months. Most of the paddlefish caught during the winter were either immature or mature females not spawning in that season. December had the highest I_f values, as can be seen in Figure 3.1.

Displacement volumes were found to be similar to the wet weight of the stomach contents (Figure 3.2). While some scatter can be seen, a linear trend exists with an R^2 of 0.79 and a regression equation of the form:

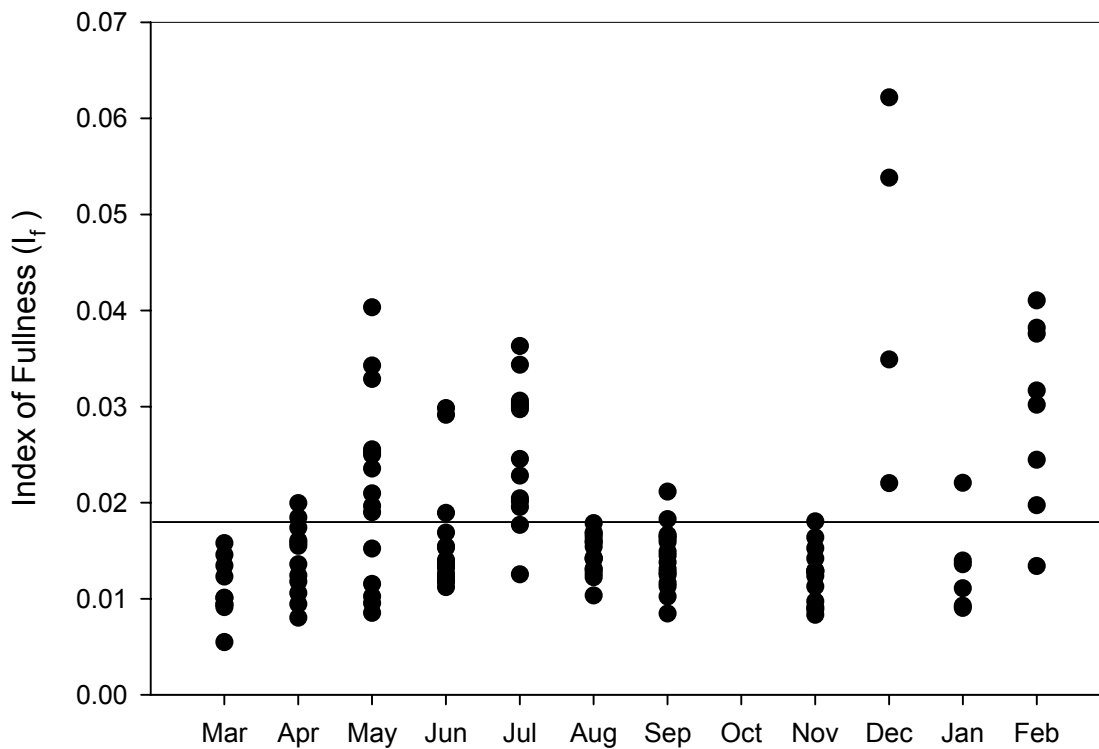


Figure 3.1. Plot of index of fullness (I_f) versus month of capture for paddlefish caught in the Mermentau River, Louisiana, in 2002-2003. Index of fullness (I_f) is calculated as the ratio of stomach weight to fish weight. Horizontal line represents mean index of fullness.

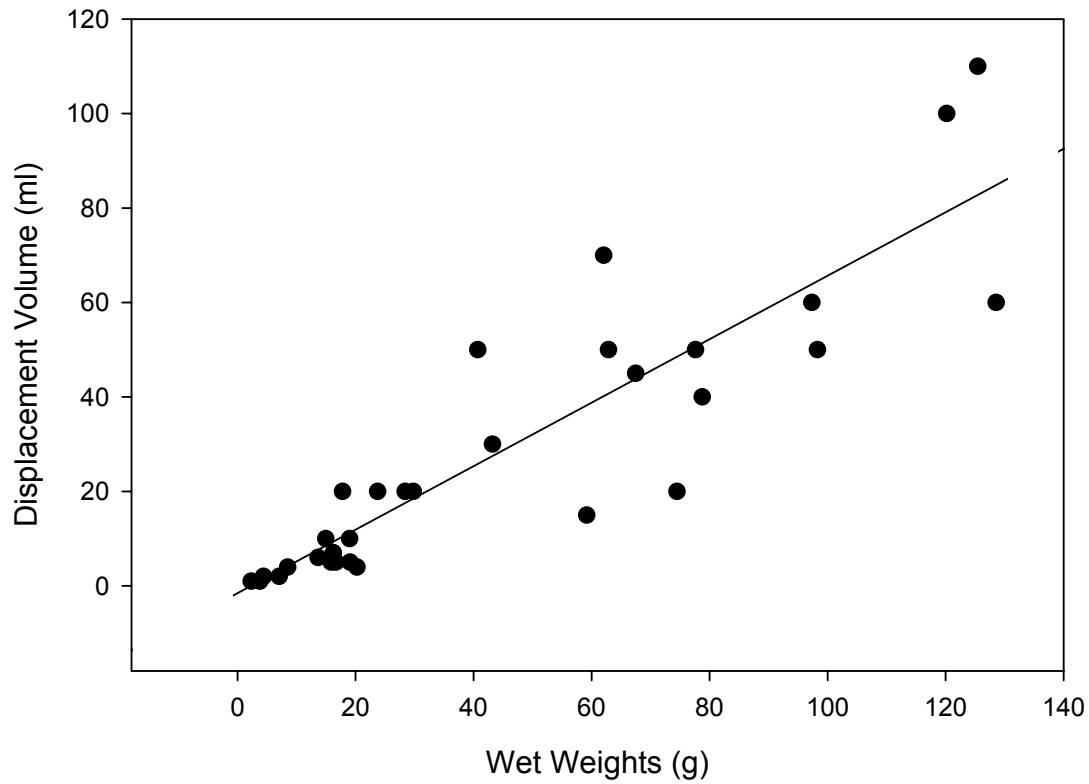


Figure 3.2. The relationship of the displacement volume and wet weight of stomach contents taken from paddlefish collected in the Mermentau River, Louisiana.

$$\text{Displacement volume} = -1.50 + 0.67(\text{wet weight}). \quad (8)$$

Wet weights of the stomach contents undoubtedly contained some frozen water that had been ingested with prey, while the displacement volume likely failed to account for some prey volume that was leached. Therefore, displacement volumes of the stomach contents would be expected to reflect leaching of fluids from the ingested and frozen prey items.

Given the general agreement between displacement volumes and weights of the frozen gut contents (Figure 3.2), the compact nature of the gut contents when excised from the stomach (Methods), and the broken nature of the gut contents (Methods), it was decided to discontinue the measuring of displacement volume if the seasonal trends in displacement volumes generally agreed with those seen in the I_f . To accomplish this comparison, I constructed a ratio of displacement volume (Dv) to stomach weight (SW) as an index of displacement volume (Dv_i):

$$Dv_i = Dv / SW \quad (9)$$

which is compared to date of capture in Figure 3.3. As noted in the figure, Dv_i generally follows a similar seasonal trend as I_f . There were peaks in mean Dv_i in May, June, and February and lows in April and August through November. The peaks and lows in mean Dv_i compare with the spread of the entire data on I_f 's presented in Figure 3.1. Therefore, I decided to focus on wet weights as the measure of gut contents and discontinue measurements of displacement volume.

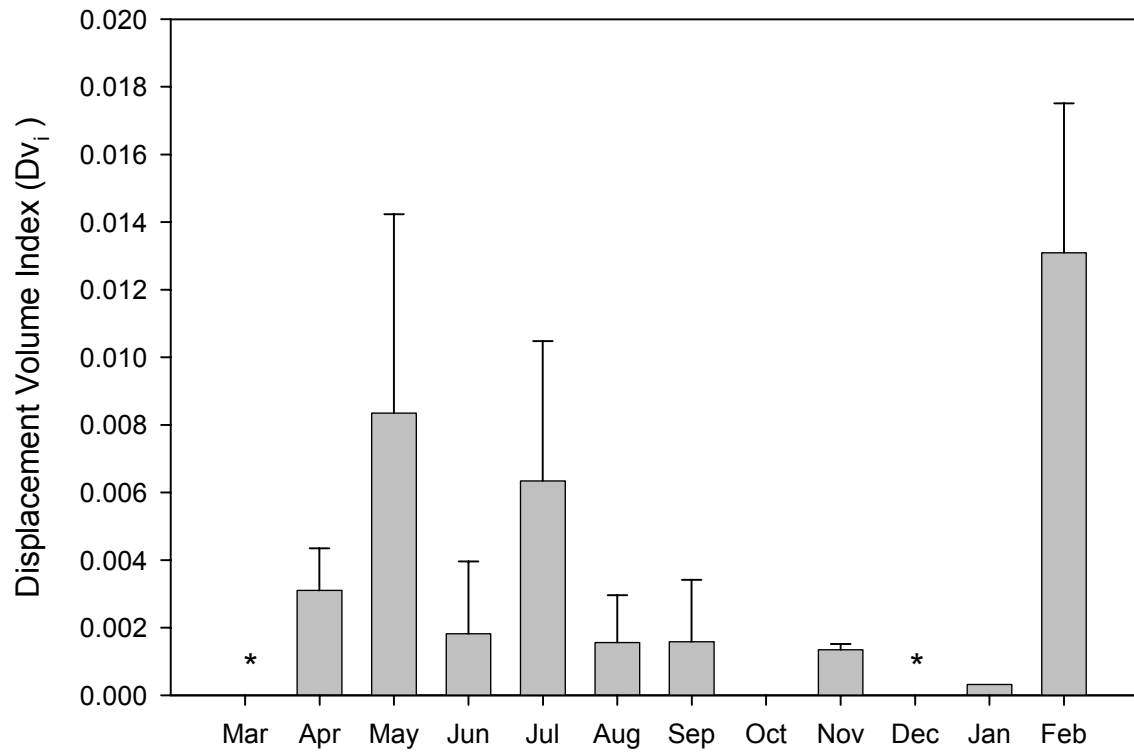


Figure 3.3. Histogram plot showing the displacement volume index (Dv_i), displacement volume divided by the weight of the fish, versus the month of capture. Asterisks represent a month where the displacement volume was not estimated. Error bars represent the standard deviation from the mean.

Seven different taxonomic groups of prey items were identified: Copepoda, Cladocera, Insecta, Ostracoda, Amphipoda, Decapoda, and diatoms (Table 3.1). Copepods were the most abundant (%N = 62%) and frequent (%O = 90%) prey item found in the stomachs, followed by cladocerans (%N = 35% and %O = 82%). Insects and ostracods were the third and fourth most abundant prey with low %N's of 1.56% and 0.80% but compactively high %O's of 68% and 38%, respectively. Amphipods and decapods were rare prey with low %N's and %O's. Diatoms (filamentous algae) had an annual %O of 9.8% (Table 3.1).

Figure 3.4 shows the mean %N for copepods and cladocerans by month. Copepods exhibited a peak in %N during the summer month of June and declined from July to February. Cladocerans exhibited an inverse relationship compared to copepods, with a low %N for the summer month of June, which increased from July to February. This pattern was also observed in the crustacean zooplankton tows taken in November, January and February.

Table 3.2 compares the mean monthly %N and %O for all prey categories for each month of capture. As expected from Figure 3.4, copepods were dominant from March 2002 to September 2002 and cladocerans were dominant from November 2002 to February 2003. While the other animal prey categories occurred, their mean monthly abundances never approached those of copepods and cladocerans. Amphipods only occurred in May 2002 (%N = 0.4, %O = 15.4) and February 2003 (%N = 0.0, %O = 28.6). Decapods only occurred in August (%N = 0.1, %O = 12.5) and September 2002 (%N = 0.0, %O = 10.0). Insects occurred in every month with low %N (less than 4%) and always had %O's above 50%. Ostracods occurred in

Table 3.1. Percent number (%N) and percent occurrence (%O) for all prey categories found in the diet of paddlefish caught in the Mermentau River, Louisiana. Filamentous algae were not counted (n.q. = not quantified) and are therefore not included in the calculation of %N.

Prey Category	% N	% O
All Stomachs		
Copepoda	62.13	90.20
Cladocera	35.44	82.35
Insecta	1.56	68.63
Ostracoda	0.80	38.24
Amphipoda	0.06	3.92
Decapoda	0.01	1.96
Filamentous Algae	n.q.	9.80

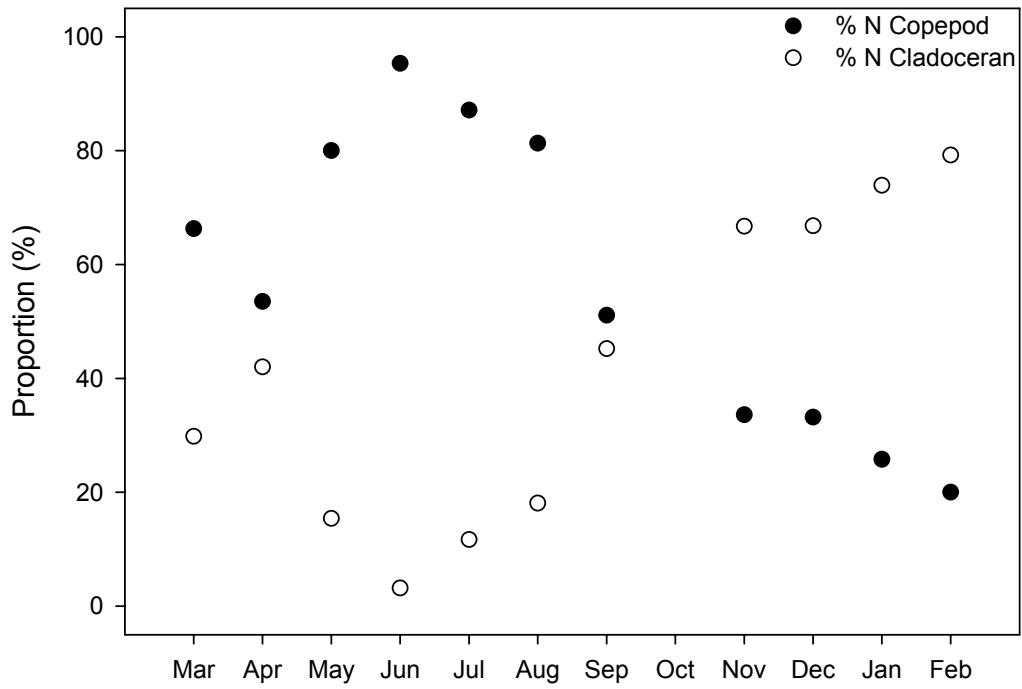


Figure 3.4. Mean percent number (% N) for copepods and cladocerans for each month of capture.

Table 3.2. Summary of the diet of paddlefish for all sampling dates. Mean percent composition by number (%N) of animal prey and mean percent occurrence (%O) of all prey are reported for each prey category. Note that filamentous algae were not counted (n.q. = not quantified) and are therefore not included in the calculation of %N. Table continues on next two pages.

Date	Paddlefish (empty stomachs)	Prey Category	% N	% O
March 2002	10 (7)	Copepoda	66.3	100.0
		Cladocera	29.8	66.7
		Insecta	2.5	66.7
		Ostracoda	1.3	66.7
		Amphipoda	0.0	0.0
		Decapoda	0.0	0.0
April 2002	12 (2)	Copepoda	53.5	80.0
		Cladocera	42.0	100.0
		Insecta	1.3	80.0
		Ostracoda	3.2	70.0
		Amphipoda	0.0	0.0
		Decapoda	0.0	0.0
May 2002	15 (1)	Copepoda	80.0	100.0
		Cladocera	15.4	76.9
		Insecta	3.6	76.9
		Ostracoda	0.6	53.8
		Amphipoda	0.4	15.4
		Decapoda	0.0	0.0
		Filamentous Algae	n.q.	60.0
June 2002	17 (5)	Copepoda	95.3	100.0
		Cladocera	3.2	75.0
		Insecta	1.5	83.3
		Ostracoda	0.0	0.0
		Amphipoda	0.0	0.0
		Decapoda	0.0	0.0
July 2002	15 (3)	Copepoda	87.1	100.0
		Cladocera	11.7	91.7

Table 3.2 cont'd

Date	Paddlefish (empty stomachs)	Prey Category	% N	% O
		Insecta	1.2	66.7
		Ostracoda	0.0	0.0
		Amphipoda	0.0	0.0
		Decapoda	0.0	0.0
August 2002	15 (7)	Copepoda	81.3	100.0
		Cladocera	18.1	87.5
		Insecta	0.2	50.0
		Ostracoda	0.3	37.5
		Amphipoda	0.0	0.0
		Decapoda	0.1	12.5
September 2002	16 (6)	Copepoda	51.1	100.0
		Cladocera	45.2	90.0
		Insecta	1.7	90.0
		Ostracoda	2.0	90.0
		Amphipoda	0.0	0.0
		Decapoda	0.0	10.0
October 2002	0	No fish caught due to Hurricane Lily and tropical storm Isidore		
November 2002	13 (1)	Copepoda	33.6	100.0
		Cladocera	66.7	91.7
		Insecta	2.0	66.7
		Ostracoda	0.7	33.3
		Amphipoda	0.0	0.0
		Decapoda	0.0	0.0
December 2002	4 (0)	Copepoda	33.2	100.0
		Cladocera	66.8	100.0
		Insecta	0.1	50.0
		Ostracoda	0.0	0.0
		Amphipoda	0.0	0.0
		Decapoda	0.0	0.0

Table 3.2 cont'd

Date	Paddlefish (empty stomachs)	Prey Category	% N	% O
January 2003	6 (2)	Copepoda	25.8	75.0
		Cladocera	73.9	100.0
		Insecta	0.3	50.0
		Ostracoda	0.0	0.0
		Amphipoda	0.0	0.0
		Decapoda	0.0	0.0
February 2003	8 (1)	Copepoda	20.0	100.0
		Cladocera	79.2	100.0
		Insecta	0.5	85.7
		Ostracoda	0.3	100.0
		Amphipoda	0.0	28.6
		Decapoda	0.0	0.0

every month except June, July, December 2002 and January 2003. While their %N was low (less than 4%), in the months they did occur, their %O was always above 30%. Sixty percent of the May stomachs contained filamentous algae, which have been tentatively identified as chain forming diatoms. Though a determination of the relative abundance and identity of these diatoms is beyond the scope of this thesis, it should be noted that these diatoms dominated the total stomach contents of most of the full May stomachs.

Apparent Ingestion Time

I used the plankton tow data for November, January, and February to estimate the apparent ingestion time, t_p . I define t_p as the time it would have taken for a paddlefish to ingest the zooplankton found in the heaviest stomachs in each of these months (Table 3.3). The basic relationship is expressed as:

$$\overline{N_n / V_n} = N_p / V_p \quad (10)$$

where $\overline{N_n / V_n}$ is the average ratio of the number of organisms in a net tow to the volume filtered by the plankton net, N_p is the total number of organisms in a stomach, and V_p is the volume filtered by the paddlefish. Equation 10 assumes that the plankton tows are representative of the concentration of plankton upon which the paddlefish had fed and that no digestion occurs in the paddlefish stomach. For the flowmeter mounted in the plankton net, the distance towed is (General Oceanics Inc. Undated):

Table 3.3. Parameters used to calculate t_p , apparent ingestion time, for the heaviest paddlefish stomachs from November, January and February. Abbreviations are: V_n , volume of water filtered by the plankton net; N_n , number of zooplankton in net; MSS, width of the paddlefish mouth; MTB, height of the paddlefish mouth; N_p , number of zooplankton found in the stomach.

Month	Tow	Plankton Net			Mouth (m)		N_p	t_p (d)
		V_n	N_n	N_n / V_n	MSS	MTB		
November	1	134.46	917.65	6.82				
	2	129.59	445.50	3.44				
	Avg			5.13	0.14	0.16	9,664	1.0
January	1	122.57	14,916.00	121.70				
	2	152.65	17,964.00	117.68				
	3	184.37	8,712.00	47.25				
	Avg			95.54	0.11	0.12	27,200	4.9
February	1	134.55	7191.36	53.45				
	2	122.54	5722.20	46.70				
	3	118.43	3981.41	33.62				
	Avg			44.59	0.11	0.11	568,000	12.0

$$\text{Distance} = [\text{Difference in the counts} \times \text{rotor constant (26,873)}] / 999,999 \quad (11)$$

and the volume of water filtered by the plankton net:

$$\text{Volume (m}^3\text{)} = [3.14 \times (\text{net radius})^2 \times \text{Distance}]. \quad (12)$$

I assume V_p can be defined as:

$$V_p = \pi \times \text{MSS} \times \text{MTB} \times R \times t_p \quad (13)$$

where R is the speed of a ram filter-feeding paddlefish (taken from Sanderson et al. 1994).

Substituting Equation 13 into Equation 10 and solving for t_p :

$$t_p = \left(\frac{N_p}{\pi \times \text{MSS} \times \text{MTB} \times R} \right) \times \frac{1}{\left[\overline{N_n / V_n} \right]}. \quad (14)$$

Substituting the appropriate values from Table 3.3 into Equation 14, I estimated t_p for the November paddlefish at approximately one day, January paddlefish at approximately five days and February paddlefish at approximately 12 days.

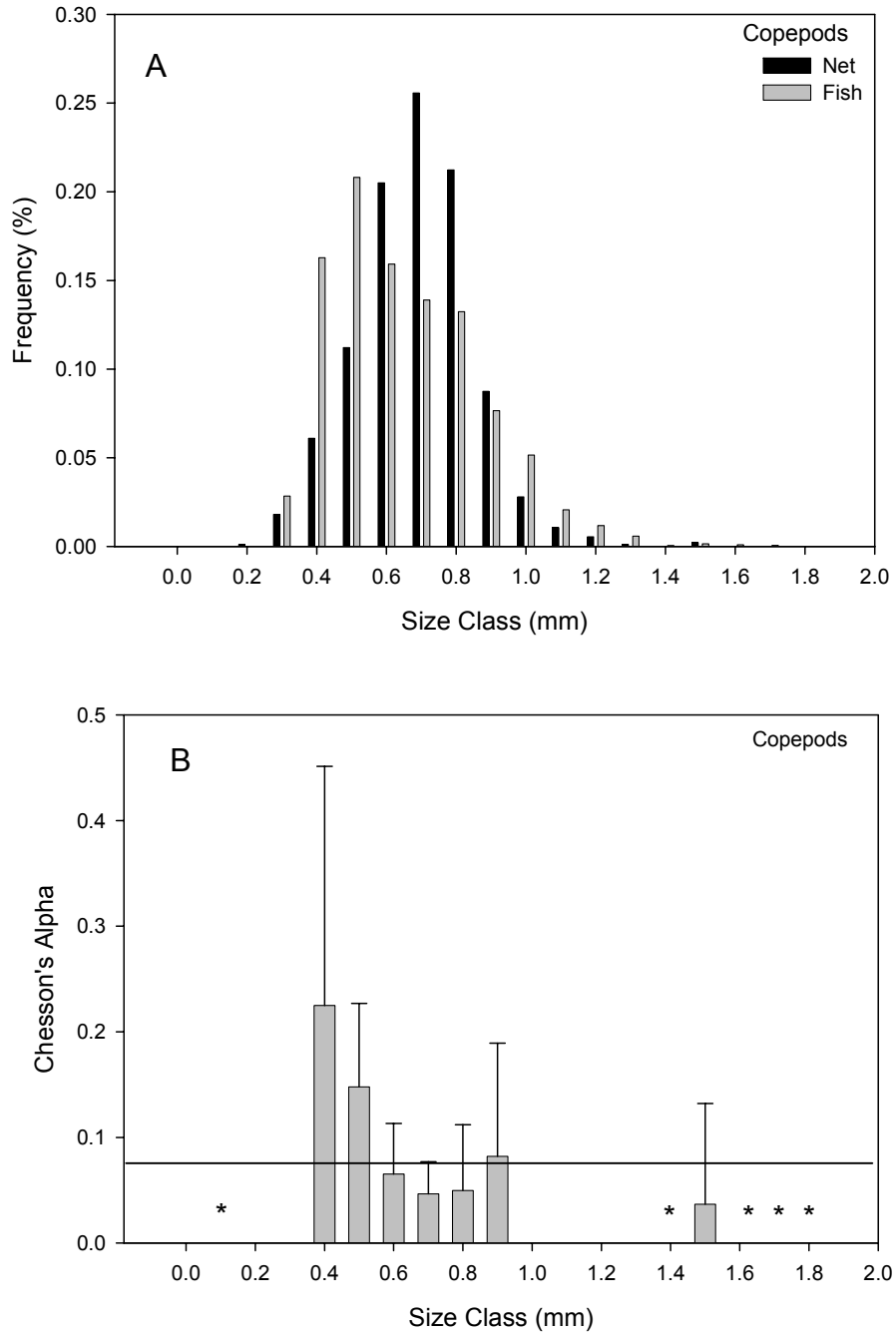


Figure 3.5. Frequency distributions (A) and size selection using Chesson's Alpha (B) for copepods from November, January and February. Horizontal bar indicates unbiased feeding ($1/m = 0.0769$). A size class with no bar indicates prey items of that size were not found in the stomachs. Asterisks indicate prey items of that size were not found in the net tows. Error bars represent the standard deviation from the mean.

Size Selectivity

Based on frequency distributions, paddlefish appeared to feed on smaller sized copepods than found in the plankton (Figure 3.5A). A peak in the 0.5 mm bin was seen in the stomachs of paddlefish, while a peak in the 0.7 mm bin was found in the plankton. However, when looking at cladocerans, paddlefish appeared to feed on the same sizes found in the plankton (Figure 3.6A). A peak occurred in the 0.4 mm bin for paddlefish stomachs and plankton. Paddlefish fed more abundantly on smaller sized copepods and cladocerans even though larger sizes occurred in the nets. Paddlefish fed on copepods and cladocerans that were no smaller than 0.2 mm.

Contrary to the graphical representation of the relative abundance of different sized copepods and cladocerans, Chesson's alpha results indicated that paddlefish were not selective feeders as seen in Figure 3.5B and 3.6B, for copepods and cladocerans respectively. A peak was seen in the frequency distribution for copepods at the 0.7 mm bin in the nets compared to the 0.5 mm bin peak in the stomachs, one might expect to see a positive selection for the smaller size class of copepods. However, based on the Chesson's alpha results, paddlefish were not actively selecting for a particular size class of copepods. This was also seen with the cladocerans. A peak was seen in the 0.4 mm bin for both the nets and the stomachs and again Chesson's alpha test showed non-selective feeding occurred.

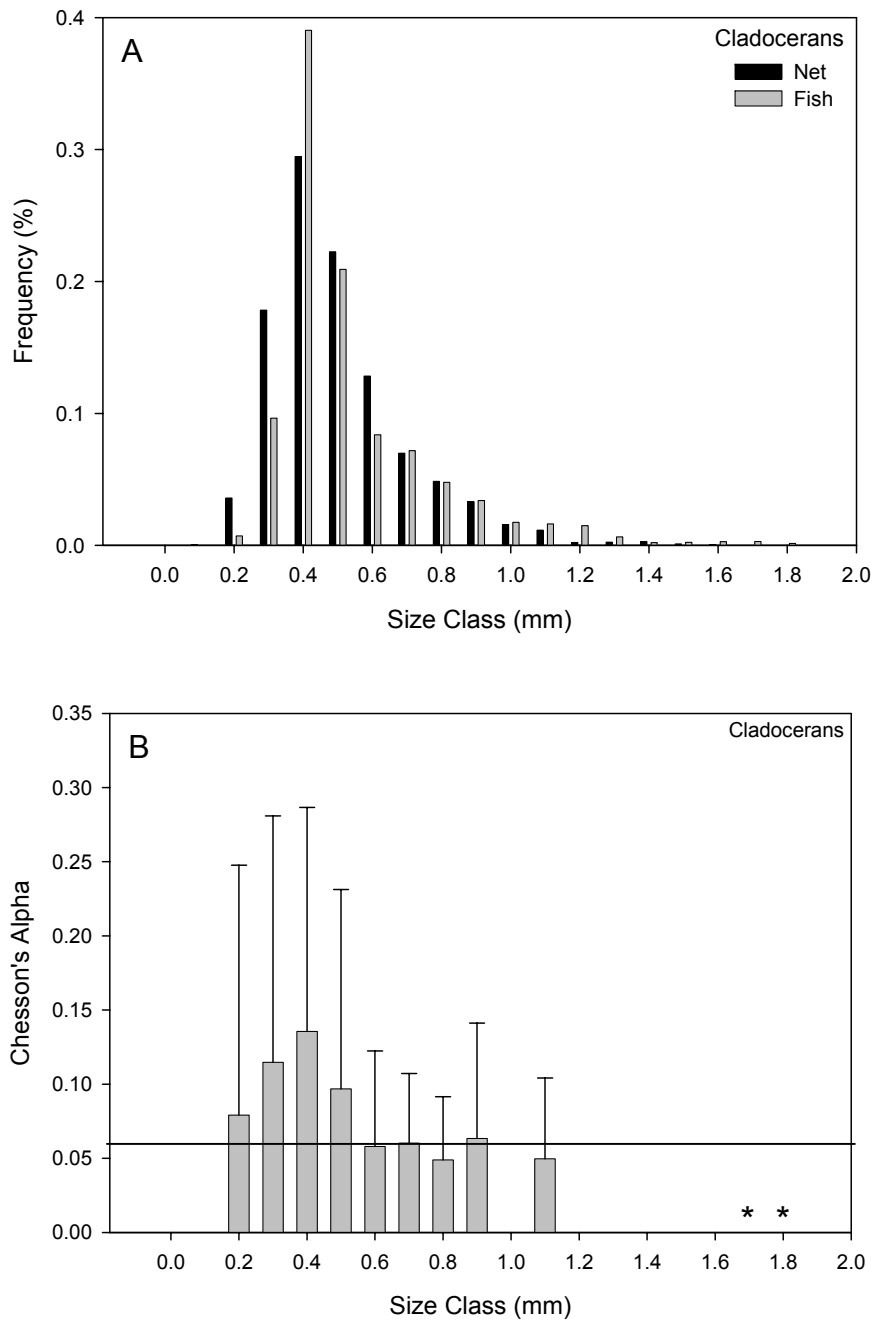


Figure 3.6. Frequency distributions (A) and size selection using Chesson's Alpha (B) for cladocerans from November, January and February. Horizontal bar indicates unbiased feeding ($1/m = 0.0625$). A size class with no bar indicates prey items of that size not found in the stomachs. Asterisks indicate prey items of that size not found in the net tows. Error bars represent the standard deviation from the mean.

Diet by Season

The ANOSIM results indicated that paddlefish had similar diets when comparing spring to summer (R-statistic: 0.167), spring to fall (R-statistic: 0.239), and fall to winter (R-statistic: 0.034). Paddlefish diets showed some separation between spring and winter (R-statistic: 0.528) and summer and fall (R-statistic: 0.633), but still showed overlap. However, a significant difference was seen when comparing the seasons of summer to winter (R-statistic: 0.965). The MDS plot (Figure 3.7) shows that summer was farther from winter than any other season (R-statistic: 0.965).

The results of ANOSIM were best described by SIMPER, which showed the similarities of the diet within, and between, seasons. Table 3.4 shows the similarities within season for six animal prey categories. Spring diets had an average similarity within season of 63.24% (where 100% is complete similarity), with copepods contributing 82.84% and cladocerans contributing 15.81% to the similarities of the diet. Summer diets had an average similarity of 86.55%, with copepods contributing 95.36% and cladocerans contributing 4.18% of the diet. Fall diets had an average similarity of 65.51%, with cladocerans contributing 58.84% and copepods contributing 39.65% to the diet. Winter diets had an average similarity of 85.74%, with cladocerans contributing 78.68% and copepods contributing 21.13% to the diet. All other groups contributed very little (< 4%) to the diet of the paddlefish over all seasons.

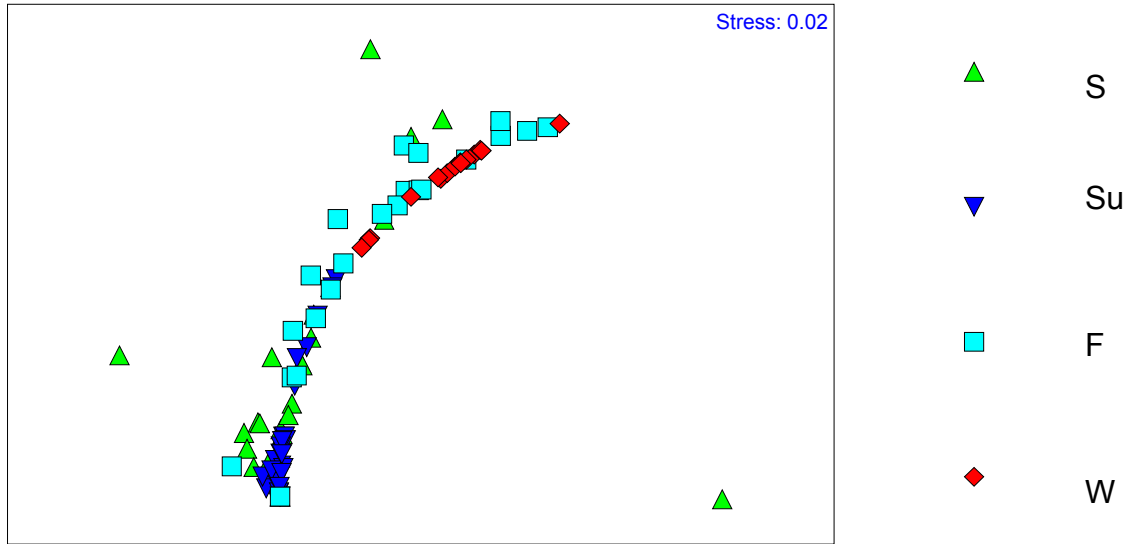


Figure 3.7. Multi-dimensional scaling plot for between season comparisons. S= spring, Su= summer, F= fall, W= winter.

Table 3.4. SIMPER results based on six animal prey category contributions to within-season similarity for diets of paddlefish collected in the Mermentau River, Louisiana. Sim/SD = Similarity/Standard deviation ratio.

Season	Prey Category	Average Similarity	Sim/SD	% Contribution	%Cumulative Contribution
Spring		63.24			
	Copepoda	52.39	1.67	82.84	82.84
	Cladocera	10.00	0.77	15.81	98.65
	Ostracoda	0.45	0.41	0.71	99.36
	Insecta	0.40	0.49	0.63	99.99
	Amphipoda	0.00	0.06	0.01	100.00
Summer		86.55			
	Copepoda	82.53	5.92	95.36	95.36
	Cladocera	3.62	0.64	4.18	99.54
	Insecta	0.40	0.62	0.46	100.00
	Ostracoda	0.00	0.08	0.00	100.00
Fall		65.51			
	Cladocera	38.54	1.59	58.84	58.84
	Copepoda	25.97	1.38	39.65	98.49
	Insecta	0.70	0.78	1.07	99.55
	Ostracoda	0.29	0.40	0.45	100.00
Winter		85.74			
	Cladocera	67.46	6.32	78.68	78.68
	Copepoda	18.12	2.02	21.12	99.81
	Insecta	0.13	0.62	0.15	99.96
	Ostracoda	0.03	0.47	0.04	100.00
	Amphipoda	0.00	0.10	0.00	100.00

Table 3.5 shows the dissimilarities of the diet between-season for six animal prey categories. Spring and summer had an average dissimilarity of 28.45% (where 100% is total dissimilarity), with copepods contributing to 55.46% and cladocerans contributing 35.97% of the difference. Spring and fall had an average dissimilarity of 46.12%, with copepods contributing to 47.04% and cladocerans contributing 46.49% of the difference. Summer and fall had an average dissimilarity of 49.63%, with copepods contributing 49.81% and cladocerans contributing 46.98% of the difference. Spring and winter had an average dissimilarity of 55.82%, with cladocerans contributing 51.12% and copepods contributing 44.86% of the difference. Summer and winter had an average dissimilarity of 64.70%, with cladocerans contributing to 49.82% and copepods contributing 49.22% of the difference. Fall and winter had an average dissimilarity of 29.18%, with cladocerans contributing 49.11% and copepods contributing 45.71% of the difference. All other groups combined contributed < 29% to the dissimilarity of the diets for all between season's comparisons. All between season comparisons showed a relatively low percentage (<56%) of difference indicating that the diets were similar. However, when looking at the comparison of summer to winter, a percentage value of 64.70% indicated that these two seasons were different from each other as seen in Figure 3.7 and based on their R-statistic values.

Diet by Stage of Sexual Maturity

The ANOSIM results indicated that paddlefish had similar diets when comparing the diets between all stages for which there were sufficient observations: stage 2 and 3 (R statistic: 0.124), stage 2 and 1 (R-statistic: 0.393), and stage 3 and

Table 3.5. SIMPER results based on six animal prey category contributions to between-season dissimilarities for diets of paddlefish caught in the Mermentau River, Louisiana. S = spring, Su = summer, F = fall, W = winter, and Diss/SD = Dissimilarity/Standard deviation ratio. Table continues on next page.

Season	Prey Category	Average Dissimilarity	Diss/SD	% Contribution	% Cumulative Contribution
S vs. Su		28.45			
	Copepoda	15.78	0.79	55.46	55.46
	Cladocera	10.23	1.03	35.97	91.43
	Insecta	1.48	0.40	5.21	96.64
	Ostracoda	0.85	0.69	2.98	99.62
	Amphipoda	0.10	0.27	0.35	99.97
	Decapoda	0.01	0.18	0.03	100.00
S vs. F		46.12			
	Copepoda	21.69	1.52	47.04	47.04
	Cladocera	21.44	1.47	46.49	93.53
	Insecta	1.76	0.47	3.81	97.34
	Ostracoda	1.12	0.86	2.43	99.77
	Amphipoda	0.10	0.27	0.22	99.99
	Decapoda	0.00	0.21	0.01	100.00
Su vs. F		49.63			
	Copepoda	24.72	1.86	49.81	49.81
	Cladocera	23.31	1.79	46.98	96.79
	Insecta	0.94	0.83	1.89	96.68
	Ostracoda	0.64	0.62	1.30	99.98
	Decapoda	0.01	0.26	0.02	100.00

Table 3.5 cont'd

S vs. W	55.82				
Cladocera	28.54	2.03	51.12	51.12	
Copepoda	25.04	2.28	44.86	95.98	
Insecta	1.30	0.34	2.32	98.30	
Ostracoda	0.84	0.69	1.50	99.81	
Amphipoda	0.11	0.29	0.19	100.00	
Su vs. W	64.70				
Cladocera	32.23	3.68	49.82	49.82	
Copepoda	31.85	3.68	49.22	99.04	
Insecta	0.51	0.87	0.79	99.83	
Ostracoda	0.09	0.64	0.14	99.97	
Amphipoda	0.01	0.36	0.02	99.99	
Decapoda	0.01	0.18	0.01	100.00	
F vs. W	29.18				
Cladocera	14.33	1.30	49.11	49.11	
Copepoda	13.34	1.28	45.71	94.82	
Insecta	0.86	0.72	2.96	97.78	
Ostracoda	0.63	0.62	2.17	99.95	
Amphipoda	0.01	0.36	0.03	99.98	
Decapoda	0.00	0.22	0.02	100.00	

1 (R-statistic: -0.045). The MDS plot (Figure 3.8) shows that the stages of sexual maturity were well mixed with no two stages being separated from each other to indicate a difference in diet. This pattern was seen even though stage 1 had a low sample size (n = 12). When it was compared to stage 2 (n = 47) and stage 3 (n = 36), paddlefish still fed similarly, which was seen in Figure 3.8 with a wide spread of stage 1 encompassing stage 2 and 3.

The ANOSIM results were best described by SIMPER, which showed the similarities of the diet within and between stages of sexual maturity based on prey items. Table 3.6 shows the similarities of the diet within-stage for six animal prey categories. Stage 1 had an average similarity of 69.70%, with cladocerans contributing 64.17% and copepods contributing 34.69% of the diet. Stage 2 had an average similarity of 70.71%, with copepods contributing 86.86% and cladocerans contributing 12.64% of the diet. Stage 3 had an average similarity of 55.11%, with copepods contributing 60.55% and cladocerans contributing 38.11% of the diet. All other groups contributed very little (< 3%) to the diet of the paddlefish over all stages. Table 3.7 shows the dissimilarities of the diet between-stage for six animal prey categories. Stage 2 and 3 had an average dissimilarity of 41.11%, with copepods contributing 50.67% and cladocerans contributing 43.98% of the difference. Stage 2 and 1 had an average dissimilarity of 46.76%, with cladocerans contributing 48.70% and copepods contributing 48.61% of the difference. Stage 3 and 1 had an average dissimilarity of 40.86%, with cladocerans contributing 49.08% and copepods contributing 45.04% of the difference. All other groups combined

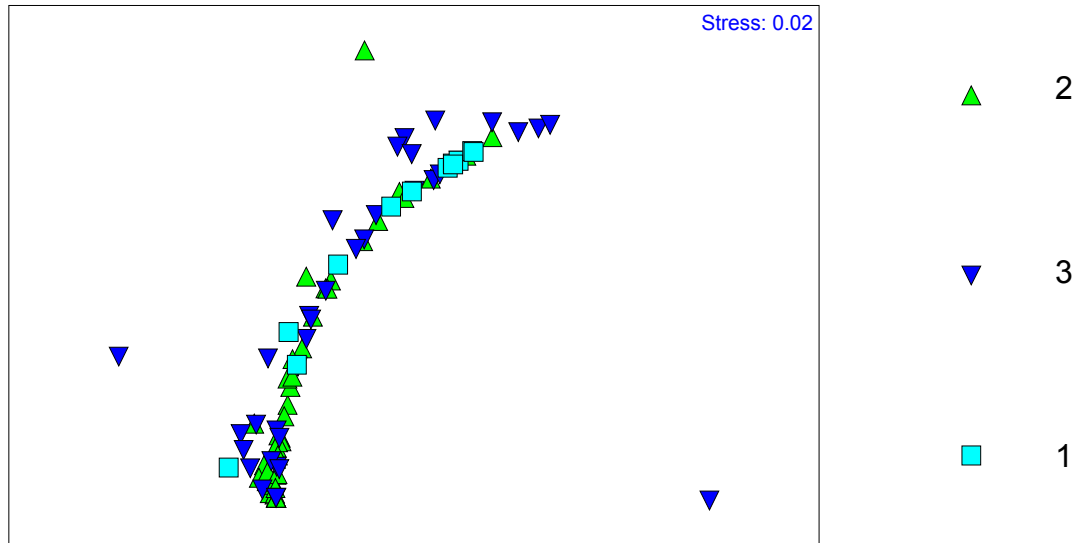


Figure 3.8. Multi-dimensional scaling plot for between stages of sexual maturity comparisons.

Table 3.6. SIMPER results based on six animal prey category contributions to within-stage similarities for diets of paddlefish caught in the Mermentau River, Louisiana. Sim/SD = Similarity/Standard deviation ratio.

Stage	Prey Category	Average Similarity	Sim/SD	% Contribution	% Cumulative Contribution
1		69.70			
	Cladocera	44.73	1.61	64.17	64.17
	Copepoda	24.18	1.94	34.69	98.86
	Insecta	0.54	1.10	0.77	99.63
	Ostracoda	0.25	0.88	0.36	100.00
	Amphipoda	0.00	0.12	0.00	100.00
2		70.71			
	Copepoda	61.42	2.12	86.86	86.86
	Cladocera	8.93	0.64	12.64	99.50
	Insecta	0.30	0.62	0.43	99.92
	Ostracoda	0.05	0.22	0.08	100.00
	Decapoda	0.00	0.03	0.00	100.00
3		55.11			
	Copepoda	33.37	1.20	60.55	60.55
	Cladocera	21.00	0.86	38.11	98.66
	Insecta	0.52	0.47	0.94	99.60
	Ostracoda	0.22	0.24	0.40	100.00

Table 3.7. SIMPER results based on six animal prey category contributions to between-stage dissimilarities for diets of paddlefish caught in the Mermentau River, Louisiana. Diss/SD = Dissimilarity/Standard deviation ratio.

Stage	Prey Category	Average Dissimilarity	Diss/SD	% Contribution	% Cumulative Contribution
2 vs. 3		41.11			
	Copepoda	20.83	1.19	50.67	50.67
	Cladocera	18.08	1.27	43.98	94.65
	Insecta	1.40	0.42	3.40	98.05
	Ostracoda	0.73	0.64	1.79	99.83
	Amphipoda	0.06	0.20	0.15	99.98
	Decapoda	0.01	0.19	0.02	100.00
2 vs. 1		46.76			
	Cladocera	22.77	1.74	48.70	48.70
	Copepoda	22.73	1.75	48.61	97.31
	Ostracoda	0.60	0.60	1.29	98.60
	Insecta	0.60	0.99	1.27	99.88
	Amphipoda	0.05	0.19	0.11	99.98
	Decapoda	0.01	0.19	0.02	100.00
3 vs. 1		40.86			
	Cladocera	20.06	1.35	49.08	49.08
	Copepoda	18.40	1.39	45.04	94.12
	Insecta	1.42	0.44	3.48	97.60
	Ostracoda	0.95	0.72	2.32	99.92
	Amphipoda	0.03	0.26	0.08	100.00

contributed < 14% to the dissimilarities of the diet for all between stages comparisons. All between stage comparisons resulted in low percentages of difference (<51%) and thus were similar in diet composition.

Based on the BVSTEP analysis, 99% of the variability of the diet for paddlefish caught in the Mermentau River was explained by copepods and cladocerans.

Discussion

This study represents the first time that the feeding ecology of paddlefish has been investigated in Louisiana waters. The feeding seasonality showed that paddlefish had two peaks in feeding, one during late spring and early summer and another one during the winter. Paddlefish mainly feed on crustacean zooplankton as found in other studies (e.g. Rosen and Hales 1981). Copepods and cladocerans comprised most of the diet of paddlefish. A “switching” effect of feeding on copepods to cladocerans seems to have occurred in which copepods dominated in the late spring and early summer and cladocerans dominated in the winter. This switching may simply reflect the dominance of these organisms in the plankton based on similarities between the gut contents and with the plankton tows taken in November, January and February. Diatoms dominated the stomachs of paddlefish in May 2003. Paddlefish diets were similar between most seasons but exhibited a difference in feeding between the summer and winter seasons. Copepods and cladocerans contributed to almost all of the similarities and dissimilarities of the diets. Paddlefish diets were similar between stages 1, 2, and 3 of sexual maturity with copepods and

cladocerans contributing to all of the similarities and differences of the diet. The evaluation of size selectivity resulted in the finding that paddlefish do not selectively feed and can be described as indiscriminate feeders.

Seasonality of feeding determined by the I_f showed that paddlefish caught in the Mermentau River had fuller stomachs during the summer and winter months (Figure 3.1). The early spring and fall months showed low I_f values apparently due to the spawning season. Feeding was extremely high for all fish caught in December. These paddlefish consisted of two immature females and two mature males. The females, because they were immature, had not left to go to the spawning grounds. The males, while mature, were only a stage 2 and 3 of maturity and may not have been ready to spawn. December had the highest I_f values which caused the seasonality trend to spike in the month of December and may not be representative of the whole population. February had a spike in I_f as well. These fish were almost entirely immature females. While these immature and non-spawning fish caused spikes in the seasonality of feeding for December and February, it is a good indication that these fish were indeed feeding and were in good condition.

My finding that paddlefish primarily feed on crustacean zooplankton is consistent with other paddlefish feeding studies (Rosen and Hale 1981, Hoxmeier and DeVries 1997, Hageman et al. 1986). I found six different prey categories in the stomachs. The most abundant prey was copepods and cladocerans that made up 97.57% of the diet of paddlefish over the entire study (Table 3.1). Overall, copepods dominated the stomachs. By month copepods dominated from March 2002 to

September 2002, then cladocerans dominated from November 2002 to February 2003 (Table 3.2). While other prey categories existed in the stomachs, they were nowhere near in %N to copepods and cladocerans. However, insects occurred in 68.63% of the stomachs and ostracods occurred in 38.24% of the stomachs. Even though insects and ostracods had a low %N they occurred almost as frequently as the copepods and cladocerans. Nematodes were also found in the stomach. These nematodes were determined to be parasitic. When diatoms occurred in May 2002, they dominated the entire stomach contents, but copepods and cladocerans were still seen.

Apparent Ingestion Time

My estimates of apparent ingestion time were dependent upon an unrealistic assumption: that paddlefish were random filter feeders. For example, it is unlikely that it took 12 days for the February paddlefish to fill its stomach with zooplankton. Rather it seems likely that the paddlefish had fed on dense patches of zooplankton. It was beyond the scope of my project to investigate the patchiness of the plankton, which has been shown to vary by a factor of 1,000 within distances of meters (e.g. Hembre and Megard 2003). However, my results suggest that future work should focus on the ability of paddlefish to find dense patches of zooplankton.

Size Selectivity

This study agrees with Rosen and Hale's (1981) finding that paddlefish feed by filtering indiscriminately but may also involve actively capture prey. They also noted that paddlefish were not restricted to crustacean zooplankton. They discuss the finding of aquatic insects, as found in this study, which supports the hypothesis

of active capture of prey. However, they conclude that more research is needed to evaluate how paddlefish feed on aquatic insects and therefore they conclusively characterize adult paddlefish as indiscriminate filter feeders. This study also found aquatic insects in the stomachs as well as other prey such as ostracods, amphipods, decapods and diatoms. More research is needed to evaluate if paddlefish actively select these organisms or if these prey are simply ingested due to impediment or non-avoidance.

Diet by Season

Copepods contributed most to the diet for spring and summer while cladocerans contributed most to the diet for fall and winter. Paddlefish seem to eat more of the copepods in the warmer months and cladocerans in the cooler months based on gut analysis. Overall paddlefish had similar diets between most of the seasons. However, paddlefish did exhibit some differences in feeding when comparing summer to winter, which can be seen by looking at the contributions of copepods and cladocerans. In the similarity table (Table 3.3) copepods (95.36%) were the dominating prey in the summer and cladocerans (78.68%) were the dominating prey in the winter. In the dissimilarity table (Table 3.4) copepod and cladoceran contributions to the differences of the diet between summer and winter were very close, 49.22% and 49.82% respectively. Together they made up 99.04% of the difference between these two seasons, thus showing that these two organisms contributed to the differences in summer and winter. Again, this is showing that paddlefish switch from feeding predominately on copepods to cladocerans.

Diet by Stage of Sexual Maturity

Although the ANOSIM results indicated that paddlefish had similar diets across all stages of sexual maturity, I feel that as paddlefish mature from stages 1 to 3 it can be seen that their feeding becomes less similar. If true, this may relate to the patterns seen by others in juvenile paddlefish (Ruelle and Hudson, 1977; Michaletz et al. 1982; Kozfkay and Scarnecchia 2002). In my study, average similarities of the diets started at 69.70% for stage 1, increased slightly to 70.71% at stage 2, and then dropped to 55.11% in stage 3. Copepods were the dominant contributor to the similarity of the diet for comparisons within-stage. When looking at between-stages, paddlefish feed very similar. Average dissimilarities percentages were very much the same: stages 2 and 3 with 41.11%, stages 2 and 1 with 46.76%, and stages 3 and 1 with 40.86%, showing that their diets are the same. Copepods dominated during stages 2 and 3 (50.67%), while cladocerans dominated during stages 3 and 1 (49.08%) and 2 and 1 (48.70%).

Overall, paddlefish feed similarly regardless of season or stage of sexual maturity. The only differences seen were the prey contributions of copepods and cladocerans. Paddlefish seem to switch between these two prey categories based on the abundance of plankton. However, paddlefish are not just ingesting these two prey categories, they are also consuming insects, ostracods, decapods, and amphipods, just in lower numbers and consumed a large quantity of diatoms in May 2003.

CHAPTER 4

SUMMARY AND CONCLUSIONS

The main objectives of this thesis were to determine the best morphometric model correlating weight with various measures of the length and girth of the fish as well as the weights of selected internal organs and to examine the feeding habits of sub adult and adult paddlefish in the Mermentau River.

Paddlefish sampled in the Mermentau River, Louisiana exhibited no effect of sex and stage of maturity on the relationship between weight and EFL. Morphometric and conservation models were created to better estimate the weight of a paddlefish. The morphometric model resulted in a three-parameter model ($r^2 = 0.97$):

$$\log W = 10.10 + 1.52 (\log EFL) + 1.21 (\log G) + 0.24 (\log VG). \quad (1)$$

The conservation model, which removed any parameters that would be harmful to the fish and included BCL as a precautionary measure to discount the impact of potential errors in obtaining field measurements, resulted in a four-parameter model ($r^2 = 0.97$):

$$\log W = -9.82 + 1.15 (\log G) + 1.39 (\log EFL) + 0.25 (\log VG) + 0.15 (\log BCL). \quad (2)$$

I believe this approach (Eq. 2) to estimating weight will benefit paddlefish stock assessment and hatchery studies. I found it to be effective and already know that the girth measurements are being used in hatcheries in Louisiana to better estimate the weight for determining the females that will be ready to spawn and therefore know when to give them hormone injections.

Reanalysis of range wide data revealed reservoir/lake paddlefish were generally heavier than river paddlefish. This may reflect denser patches of zooplankton in reservoir/lake systems and greater paddlefish foraging efficiency. In addition my calculations of apparent ingestion time done in Chapter 3 indirectly suggests that paddlefish were able to locate dense patches of zooplankton.

The main objectives for the second part of my thesis were to examine the feeding habits of sub adult and adult paddlefish in the Mermentau River. Specifically I was interested in 1) identity analysis and size distribution of the prey items by functional groups and 2) effect of season and stage of paddlefish maturity on the composition of the diet. My major findings for evaluating the feeding ecology of paddlefish were as follows: paddlefish had two seasonal peaks in feeding, one at the end of spring through the summer and the other during the winter. Paddlefish mainly fed on crustacean zooplankton as found in other studies. Copepods and cladocerans explained 99% of the variability of the diet of paddlefish. A “switching” effect of feeding from copepods to cladocerans was found with copepods dominating in the summer and cladocerans dominating in the winter. Diatoms dominated the stomachs in May 2003.

Paddlefish diets were similar between seasons but exhibited a difference in feeding between the summer and winter seasons. Copepods and cladocerans contributed to the similarities and dissimilarities of the diets when comparing season. Paddlefish diets were similar between all stages of sexual maturity with copepods and cladocerans contributing to the similarities and differences of the diet. The evaluation of size selectivity resulted in finding that paddlefish do not selectively feed and can be described as indiscriminant feeders.

Recommendations for Future Research

The methods used in this study to evaluate the diet of paddlefish were successful. The use of gill nets with a mesh of five and six inches was an effective way to capture paddlefish. Environmental conditions should be taken in future studies to determine if temperature, for example, will have any effect on the ingestion ability of a paddlefish. Also, future studies should conduct plankton tows on every trip to evaluate the prey type or size selectivity of paddlefish. Plankton tows can also be evaluated to determine if the switching effect seen in this study holds true in the water column as well as in the stomach contents. Inter-gill raker distance should also be evaluated to determine the size range of organisms a paddlefish can ingest. Future research on paddlefish feeding ecology in Louisiana should be conducted in different locations and compared. This information may prove useful to management implications as well as restocking programs.

An area of interest for future research in Louisiana is migration of paddlefish. I would like to see a project that tracks the movement of paddlefish in Louisiana. Paddlefish that are raised in hatcheries are tagged with coded wire tags that can be used in telemetry projects. Also, a method of using some kind of tag with a receiver could be used to track movements. This data could give biologists an idea of where paddlefish migrate for spawning and how far they move in a day. This future research could be helpful in protecting spawning habitat.

This study was performed based on the MICRA paddlefish studies and I would recommend that these results be used to address the populations of paddlefish stocks

throughout the Mississippi River drainage area. This information may help in growth studies as well as restocking programs.

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VITA

Nicole Adele Smith was born on February 11, 1979, in San Leandro, California. She is the daughter of Janice Johnson and Timm Miller, and has a sister Kimberleigh and a twin brother Kevin. Nicole moved to Louisiana when she was ten with her mother, stepfather, Carroll Johnson, and her brother. She graduated from Woodlawn High School, Baton Rouge, in 1997 with top honors. In December of 1999, Nicole was married to Mr. Brandon Smith. Nicole received her Bachelor of Science degree in wildlife and fisheries from Louisiana State University in December of 2001. She began her pursuit of a master's degree immediately in the Department of Oceanography and Coastal Sciences at LSU in the spring of 2002. During her career as a graduate student, Nicole has worked with the Louisiana Sea Grant College Program's Native Fish in the Classroom project. This project is teaching middle school and high school students how to raise paddlefish, a native fish to Louisiana's waters, and return them to the hatchery for restocking. In August 2003, Nicole gave birth to her first child, Autumn Smith. Nicole is currently a graduate assistant in the Coastal Fisheries Institute and plans to pursue a career in wildlife and fisheries upon graduating.