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SHOVELNOSE STURGEON REPRODUCTIVE ECOLOGY IN THE LOWER PLATTE RIVER, NEBRASKA

By

Mathew L. Rugg

A THESIS

Presented to the Faculty of

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In Partial Fulfillment of Requirements

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Under the Supervision of Professor Mark A. Pegg

Lincoln, Nebraska

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# SHOVELNOSE STURGEON REPRODUCTIVE ECOLOGY IN THE LOWER PLATTE RIVER, NEBRASKA

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University of Nebraska 2013

Advisor: Mark Pegg

Biodiversity and abundance of freshwater organisms are experiencing drastic declines. Anthropogenic disturbances have altered the natural flow regimes of large rivers, and have led to declines in species that rely on elements of natural flow. Similarly, shovelnose sturgeon distribution has diminished in the last 100 years due to habitat alteration, overharvest, and water contamination. To fully understand the status and viability of a fish population, basic knowledge of a fish's reproductive strategy is needed. Aspects of reproduction that should be understood to manage for sustainability include maturation, fecundity, and spawning dynamics. There is currently little published information on age/size of maturity and fecundity of shovelnose sturgeon, and no such work on sturgeon in the Platte River. Therefore, the objective of this research was to characterize aspects of the reproductive ecology of shovelnose sturgeon in the Lower Platte River. Additionally, I assessed the validity of age estimates from fin ray cross sections to address age-related questions of reproduction using marginal increment analysis. Male shovelnose sturgeon reach maturity at a minimum fork length of 453 mm, and age-6. Males appear to spawn every three years once they have reached maturity. Female shovelnose sturgeon reached maturity at a minimum fork length of 449 mm, and age-6. Females appear to spawn every four to six years once they have reached maturity. Total fecundity of females was  $16,098 \pm 1103$  (mean  $\pm$  SE), and egg size was  $2.401 \pm 0.051$

mm (mean + SE). Fecundity of female shovelnose sturgeon was positively correlated with fish size (length and weight) and age, with weight being the best predictor of fecundity. The proportion of shovelnose sturgeon in spawning condition peaked during spring (March-May) and fall (September-October), indicating that shovelnose sturgeon spawning activities in the Lower Platte River may be bimodal. Monthly marginal increment measurements from fin rays did not display a yearly sinusoidal curve that would be expected if translucent and opaque bands represented 1 year of somatic growth. Therefore, the current method and interpretation of fish age from fin rays is likely leading to inaccurate age estimates.

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## CHAPTER 1: GENERAL INTRODUCTION AND STUDY OBJECTIVES

Biodiversity and abundance of freshwater organisms are experiencing drastic declines (Ricciardi and Rasmussen 1999; Jenkins 2003; Dudgeon et al. 2006). Anthropogenic disturbances have altered the natural flow regimes of large rivers (Dudgeon et al. 2006; Vorosmarty et al. 2010), and have led to declines in species that rely on elements of natural flow (Poff et al. 1997; Lytle and Poff 2004). For example, sturgeons and paddlefish (Order Acipenseriformes) are among the most endangered fishes around the world. All of the 27 extant species are listed under the Convention on International Trade in Endangered Species (CITES) as either Appendix I or II, resulting in regulation of any commercial trade (Pikitch et al. 2005). Gravid sturgeon and paddlefish females are targeted and harvested for their valuable black egg caviar. The collapse of the Caspian Sea fishery has recently directed harvest towards more viable North American populations such as the shovelnose sturgeon *Scaphirhynchus platyrhynchus* (Keenlyne 1997; Quist et al. 2002; Pikitch et al. 2005; Colombo et al. 2007).

The shovelnose sturgeon, smallest of all North American sturgeons, has inhabited the Mississippi and Missouri rivers and their tributaries for over 100 million years (Bailey & Cross 1954). Shovelnose sturgeon distribution has diminished in the last 100 years due to habitat alteration, overharvest, and water contamination. Shovelnose sturgeon have been extirpated in three states, are fully protected in four states, and are considered rare, threatened, or species of special concern in eight states (Keenlyne 1997). On October 1, 2010, the U.S. Fish & Wildlife Service (USFWS) listed shovelnose sturgeon as threatened under the similarity of appearance (SOA) provisions of the Endangered Species Act of 1973. This effectively shut down commercial harvest of shovelnose sturgeon where they coexist with the endangered pallid sturgeon *S. albus*

(USFWS 2010). Prior to the enactment of the SOA provision, seven states within the range of shovelnose sturgeon allowed commercial and recreational harvest, while an additional five states (i.e., Kansas, Minnesota, Montana, Nebraska, and Wyoming) allowed recreational harvest only (Keenlyne 1997), and currently still allow recreational harvest.

Nebraska anglers have demonstrated an interest in both targeting and harvesting shovelnose sturgeon (Holland and Peters 1994; Latka 1994; Peters and Parham 2008). For example, shovelnose sturgeon sport fishing has been documented within the lower 160 km of the Platte River, Nebraska and immediately below its confluence with the Missouri River (Latka 1994). Holland and Peters (1994) conducted creel surveys in 1992 and 1993 and reported that shovelnose sturgeon angling and harvest is a recreational component of the Lower Platte River. Shovelnose sturgeon comprised 4 percent in 1992 and 5 percent in 1993 of the angler catch. Anglers harvested over 73 percent of recreationally caught sturgeon in both years (Holland and Peters 1994).

Proper management of shovelnose sturgeon requires knowledge of all of its life stages. However, there is currently no published information describing reproduction of shovelnose sturgeon in the Lower Platte River. Thus, the purpose of this research was to examine the reproductive ecology of shovelnose sturgeon within the Lower Platte River. Specifically, the objectives were to define the reproductive characteristics of shovelnose sturgeon in the Lower Platte River (Chapter 2), and to address age-related questions of reproduction (e.g., age at maturity, relations between age and reproductive output), I assessed the validity of age estimates from fin ray cross sections (Chapter 3).

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## CHAPTER 2: LIFE HISTORY TRAITS OF SHOVELNOSE STURGEON IN THE LOWER PLATTE RIVER, NEBRASKA.

### ABSTRACT

Sturgeons and paddlefish in the Order *Acipenseridae* are among the most endangered fishes around the world, and shovelnose sturgeon *Scaphirhynchus platyrhynchus* distributions have diminished over the last 100 years. An understanding of reproductive life history strategies is vital for managing fish populations. However, aspects of reproductive ecology in shovelnose sturgeon in the Lower Platte River, such as maturation, fecundity, egg size, and spawning dynamics, have not been defined. We used trammel nets and trotlines to capture shovelnose sturgeon in the Lower Platte River during 2011 and 2012. Female sturgeon reached maturity at age-6 and at a minimum length of 449 mm. The average female spawning cycle was four to six years. The average egg count for mature females was  $16,098 \pm 1103$ , and egg size was  $2.401 \pm 0.051$  mm. Total fecundity was positively correlated with length ( $r^2=0.528$ ;  $p<0.0001$ ), weight ( $r^2=0.8023$ ;  $p<0.0001$ ), and age ( $r^2=0.1535$ ;  $p=0.0293$ ). However, fish size and age did not have an effect on egg size (length:  $p=0.0824$ ; weight:  $p=0.0675$ ; age:  $p=0.1811$ ). Male shovelnose sturgeon also reached maturity at age-6 and at a minimum length of 453 mm. Males appear to exhibit a three year spawning cycle once they have reached maturity. The largest proportion of reproductively viable females and males occurred in the spring (March-May) and fall (September-October) in both years. Compared to other populations, shovelnose sturgeon in the Lower Platte River are maturing at a shorter length and younger age, and spawning less frequently, potentially putting them at more risk for population declines from harsh environmental conditions or overharvest than in other systems.

## INTRODUCTION

Fish populations decline when viable adults are removed, causing a reduction in reproductive ability and therefore a reduction in sustainability (Ricker 1954). Sturgeons and paddlefish (Order Acipenseriformes) are among the most endangered fishes around the world. Specifically, shovelnose sturgeon *Scaphirhynchus platorynchus* distribution has diminished in the last 100 years due to habitat alteration, overharvest, and water contamination. Shovelnose sturgeon have been extirpated in three states, are fully protected in four states, and are considered rare, threatened, or species of special concern in eight states (Keenlyne 1997). Facilitating improvements in reproductive potential may help compensate for these declines (Colombo et al. 2007), but a current lack of information limits conservation and management efforts.

Life-history theory attempts to explain how reproductive strategies are shaped by environmental and biotic conditions. Winemiller and Rose (1992) proposed a triangular continuum of life-history strategies with three endpoints. Opportunistic strategists are characterized as being small, rapidly maturing, and short lived. Periodic strategists are larger, highly fecund, and have longer life spans. Finally, equilibrium strategists are of intermediate size that often exhibit parental care and produce fewer but larger offspring. Sturgeon species are nearest the periodic endpoint of the life-history continuum; however, shovelnose sturgeon possess specific traits that differ from other sturgeon species, such as a smaller size and earlier maturation (Keenlyne 1997). These characteristics may position shovelnose sturgeon more towards the opportunistic end of the continuum (Tripp et al. 2009).

There is little known about the life-history traits of shovelnose sturgeon in the Lower Platte River. However, specific life-cycle stages of shovelnose sturgeon in other river systems have been investigated. The capture of shovelnose sturgeon in spawning condition indicates that they likely spawn in late April to June when water levels rise and temperatures reach 16.9–20.5°C (Dryer and Sandvol 1993; Keenlyne 1997; Tripp et al. 2009). Recently, Tripp et al. (2009) found evidence that spawning may also occur in autumn in the Middle Mississippi River. However, the magnitude and overall contribution to the population from the autumn-spawned cohorts is unknown. Males become mature at a fork-length of approximately 450 mm to 530 mm (Moos 1978; Colombo et al. 2007; Tripp et al. 2009) and at an age of 5 to 8 years (Keenlyne 1997; Koch et al. 2009; Tripp et al. 2009). Females become mature at a fork length of 475 mm to 600 mm (Moos 1978; Kennedy et al. 2006; Colombo et al. 2007; Koch et al. 2009; Tripp et al. 2009) and at an age of 6 to 9 years (Keenlyne 1997; Koch et al. 2009; Tripp et al. 2009). Mature males appear to have a two year spawning cycle, whereas females are thought to have a three to four year spawning cycle (Tripp et al. 2009). Shovelnose sturgeon make upstream movements to spawn, and spawning is thought to occur over hard substrates (Keenlyne 1997). Fertilized eggs adhere to the nearby substrate (Holland and Huston 1983), larvae hatch after three to five days (Snyder 1994) and immediately begin to drift (Moyle and Cech 1988; Kynard et al. 2002) for four to five days (Kynard et al. 2002) (Figure 2.1).

Reproductive potential represents the ability of a fish stock to produce viable offspring that may recruit to the adult population or fishery (Trippel 1999). Larger and older individuals of some fish species produce larvae that have a substantially better probability of survival than do larvae from younger fishes. As female fish get larger and older, they produce eggs with greater amounts of energy-rich lipids. These lipids provide larvae sustenance after the yolk sac is used up and therefore increases survival (Berkeley et al. 2004; Birkeland and Dayton 2005). Fecundity



of shovelnose sturgeon has been shown to be positively correlated with length (Kennedy et al. 2006) and weight (Kennedy et al. 2006; Tripp et al. 2009). Additionally, Gisbert (2000) found a positive correlation between egg size and total length, body weight, and yolk sac volume of newly hatched Siberian sturgeon *Acipenser baeri* larvae.

Information on egg production provides essential parameters for stock assessment and population viability models. These models improve our understanding of population dynamics and allow for the impact of management actions to be predicted (Kennedy et al. 2006). Pine et al. (2001) used age-structured models to evaluate long-term population trends of Gulf of Mexico sturgeon *Acipenser oxyrinchus desotoi* in the Suwannee River, Florida and concluded that this population of Gulf of Mexico sturgeon was expanding, but that there was a need to define specific reproductive potential relations to properly evaluate the status of the population. Goto et al. (in review) included basic reproductive parameters (e.g., average fecundity, size at maturity) to create an individual-based model to assess the ecological risk of altered hydrology on shovelnose sturgeon sustainability in the Lower Platte River. The inclusion of specific reproductive potential parameters (i.e., fecundity, egg size) would improve shovelnose sturgeon viability models for the Lower Platte River by providing a means to predict fecundity and egg size based on fish size, age, and condition. Shifts in population dynamics (e.g., size and age structure, condition) and the resulting shifts in reproductive output are not accounted for without the inclusion of reproductive potential parameters.

Distinct relations between adult abundance and reproductive success are often weak or non-existent in populations until populations become very small (Koslow et al. 1987; Koslow 1992). Detection of these relations often comes too late, when the status of the species has long been in decline. For species with specific spawning requirements, either access to or the

availability of reproductive areas may negatively interact with reductions in mature adults to hasten population declines (Birnstein 1993). Shovelnose sturgeon are currently declining and the species has been extirpated or is at risk of extirpation from considerable portions of its native range (Keenlyne 1997). It is important that elements influencing shovelnose sturgeon reproductive potential be defined so management actions can be implemented before populations become so small that they are no longer sustainable.

A common goal among fisheries agencies is to maintain a sustainable fish population. Basic knowledge of a fish's reproductive strategy is needed to fully understand the status and viability of that fish population (Bryan et al. 2007). Aspects of reproduction that should be understood to manage for sustainability include maturation, fecundity, and timing and frequency of spawning. There is currently little published information on maturity and fecundity of shovelnose sturgeon, and no such work on sturgeon in the Platte River. Therefore, the goal of this study was to characterize key aspects of the reproductive cycle of shovelnose sturgeon in the Lower Platte River. Specifically, my objectives were to:

- 1) Determine size and age at sexual maturity;
- 2) Estimate fecundity and egg size of mature, female shovelnose sturgeon and determine if any relations of fecundity and egg size with fish length, weight, age, and condition exist;
- 3) Calculate gonadal somatic index (GSI) for male and female shovelnose sturgeon in different stages of gonadal development;
- 4) Determine the time of year when shovelnose sturgeon spawn in the Lower Platte River; and
- 5) Determine how frequently shovelnose sturgeon in the Lower Platte River spawn once they have reached sexual maturity.

These results will provide an understanding of life history strategies specific to shovelnose sturgeon in the Lower Platte River and will provide managers vital information needed to make management decisions.

### STUDY SITE

The Platte River is an alluvial, sand-bottomed, braided river system formed by the confluence of the North Platte and South Platte rivers. The Platte River drains over 230,000 km<sup>2</sup> from the east slope of the Rocky Mountains in Colorado and Wyoming across the entire state of Nebraska until it drains into the Missouri River. A dominant characteristic of the Platte River is that it is a dynamic system with shifting sand that creates and moves sand bars, alters channel dimensions, and continually changes habitat quantity, quality and availability (Galat 2005). The entire system has been affected by anthropogenic alterations in the form of power generation structures and irrigation diversions. The Lower Platte River, defined as the stretch between the Loup River confluence with the Platte River near Columbus, Nebraska to the confluence with the Missouri River near Plattsmouth, Nebraska (Figure 2.2), is characterized by continuous but variable flows, with base flows coming from the Loup and Elkhorn Rivers, and the Loup River Power Canal (Holland and Peters 1989; Galat 2005). The Loup River Power Canal causes drastic downstream, diel changes in water depth, water velocity, and cover availability due to hydropeaking to meet electricity demands (Holland and Peters 1989).

### METHODS

Shovelnose sturgeon were sampled from the Lower Platte River (Figure 2.2) from April to November during 2011 and March to November in 2012. Fish were captured using drifted

trammel nets (38.1-m long with 2.5-cm and 20.3-cm inner and outer bar mesh) and stationary trotlines (32-m long with 20 baited hooks). For each sturgeon captured, fork length (FL) was measured to the nearest millimeter and mass was measured to the nearest gram. The leading, left pectoral fin ray was removed from all shovelnose sturgeon and was later used to estimate fish age in years.

The first 20 shovelnose sturgeon captured each month were euthanized, placed on ice, and brought back to the laboratory to investigate reproductive ecology. Additional shovelnose sturgeon were collected as needed until there were five individuals present per 25-mm length group. The gonads of each shovelnose sturgeon were examined by making a midventral incision from the anus to the pelvic girdle. Gonads and associated fat from each sturgeon were photographed, removed, and weighed to calculate gonadosomatic index (GSI), calculated as:

$$GSI = \frac{\text{gonad and gonadal fat mass}(g)}{\text{total body mass}(g)} \times 100.$$

Photographs of gonads were used to categorize each gonad into developmental stages based on characteristics described by Colombo et al. (2007) and Tripp et al. (2009) (Table 2.1).

Individuals were classified as spawners if they had fully mature eggs or sperm in their gonads, showed evidence of previously carrying mature gametes (i.e., presence of atretic oocytes), or were recently spent. Conversely, individuals were classified as non-spawners if they did not have fully mature eggs or sperm in their gonads, showed no evidence of previously carrying mature gametes (i.e., presence of atretic oocytes), and were not recently spent. Fecundity for black egg (stage FIV) females was quantified by removing five 1-g samples from each ovary and counting the number of eggs in each subsample. Each 1-g sample was taken at equally spaced

intervals along the longitudinal axis of each gonad. The mean number of eggs per gram was multiplied by the total weight of both ovaries to estimate the total egg count. The diameter of 30 eggs from each of the 1-gram samples was measured using an optic micrometer and a dissecting microscope. The mean diameter of all measured eggs was calculated and used as an estimate of mean egg size for each female from which the eggs were collected.

In addition to visual inspection of the gonads, a histological analysis was performed on a subsample of gonads. This approach provided insight into the development of the spermatozoa and the oocytes in the gonads, which is critical to understand reproductive development (Colombo et al. 2007). Histological analysis also provided a means to validate visual assessments of gonad stage. A gonad tissue sample was taken from the anterior most one-third of the right gonad. Samples were preserved and processed according to methods outlined by Wildhaber et al. (2007). Histology slides were viewed under a compound microscope with a top-mounted digital camera. Images of each histological gonad section were taken and later used, in tandem with whole gonad photographs, to categorize the gonad into a developmental stage based on characteristics described by Tripp et al. (2009) and Colombo et al. (2007) (Table 2.1; Appendix A).

Regression analysis was used to determine if size or age of stage IV females correlated to egg size, fecundity, and/or GSI. Egg size and fecundity were regressed against GSI to determine if energetic investments in gonad development were put towards producing more eggs or producing larger eggs. The alpha level for all analyses was set at  $p \leq 0.05$ .

## RESULTS

A total of 409 shovelnose sturgeon were evaluated in 2011 and 2012 (377 to 725 mm FL). There were 197 females captured, 207 males, and 5 hermaphroditic individuals. The male to female sex ratio did not differ from 1:1 ( $\chi^2=0.2475$ ;  $p=0.6188$ ).

Females of all reproductive stages except Stage FV (running ripe) were collected in this study. There was a wide range of fork lengths and ages for each reproductive stage (Table 2.2). Female fork lengths ranged from 377 to 702 mm. The shortest female spawner was 449 mm FL. Fifteen females (60%) within the 500 mm FL group were classified as spawners (Figure 2.3). The median age of females was 10 years and ranged from 3 to 16 years. Minimum age at maturity in females was age-6 ( $n=1$ , 20%) and 58% of the age-10 females were deemed spawners (Figure 2.4). Gonadosomatic index was greatest for females in the FIV stage of gonad development (mean GSI=13.84, SE=0.45). Mean GSI was lowest in Fv females (mean GSI=1.21, SE=0.72), but did not statistically differ from FVI ( $t_{191}=0.16$ ,  $p=0.8750$ ) or FII females ( $t_{191}=1.47$ ,  $p=0.1442$ ) (Figure 2.5).

Sturgeon representing all stages of male reproduction (Mv-MIII) were captured and were represented by a wide range of fork lengths and ages (Table 2.2). Males ranged in size from 439 to 725 mm FL. The 450-mm FL length group was the smallest group that contained mature, with 3 individuals (20%) classified as spawners. The shortest male spawner was 453 mm FL. Over half (65%) of the males were classified as spawners once they reached the 600-mm length group (Figure 2.3). Age estimates for males ranged from 4 to 15 years with a median of 9 years. The minimum age at first maturity was age-6 ( $n=2$ , 20%) and over half (58%) of males were classified as spawners by age-10 (Figure 2.4). Gonadosomatic index differed between all male stages of gonad development. Males in the MII stage had a mean GSI greater than all

other stages (mean GSI =2.54, SE=0.14), and males in the Mv stage had a mean GSI lower than all other stages (mean GSI=0.49, SE=0.15) (Figure 2.5).

Thirty three individuals (8 %) of the total catch were determined to be stage FIV females after dissection. Fork lengths for stage FIV females ranged from 449 to 703 mm, and mean fork length was 595 mm (Table 2.2). Age was estimated for 32 of the FIV females and estimates ranged from 8 to 16 years with a median of 10.5 years (Table 2.2). Mean fecundity for FIV females was  $16,098 \pm 1103$  eggs (mean  $\pm$  SE). Fecundity was positively correlated with length ( $r^2=0.528$ ;  $p<0.0001$ ), weight ( $r^2=0.8023$ ;  $p<0.0001$ ), and age ( $r^2=0.1535$ ;  $p=0.0293$ ) (Figure 2.6). Mean egg size for FIV females was  $2.401 \pm 0.051$  mm (mean  $\pm$  SE). No relation existed between egg diameter and length ( $r^2=0.0994$ ;  $p=0.084$ ), weight ( $r^2=0.1107$ ;  $p=0.0675$ ), or age ( $r^2=0.0608$ ;  $p=0.1811$ ) of shovelnose sturgeon (Figure 2.7). Gonadosomatic index was positively correlated with weight ( $r^2=0.1689$ ;  $p=0.0216$ ), egg size ( $r^2=0.6282$ ;  $p<0.0001$ ), and fecundity ( $r^2=0.2432$ ;  $p=0.0048$ ) (Figure 2.8 and 2.9).

The proportion of shovelnose sturgeon with mature, spawning-ready gametes (MII and FIV) peaked during May, September, and October in 2011. The highest proportion of individuals with mature gametes in 2012 occurred in March, April, and September (Figure 2.10). All peaks in the proportion of MII and FIV shovelnose sturgeon coincided with temperatures between 15.70 and 19.93°C.

The male reproductive cycle appeared to be completed within three years, as approximately one-third of all males longer than the minimum length at maturity contained fully developed sperm in both 2011 (30%) and 2012 (35%) (Table 2.3). Female shovelnose sturgeon appeared to spawn every four to six years based on the proportion of females above the minimum length at maturity that contained black eggs each year. Twenty six percent of females

larger than the minimum length at maturity were carrying black eggs in 2011, while only 15 percent had black eggs in 2012 (Table 2.3).

Five of the 226 fish (2.2%) that had histological analysis completed on their gonads were classified as hermaphrodites. Lengths of hermaphroditic individuals ranged from 509 to 631 mm FL. These individuals all contained small areas of female gametes embedded within testicular tissue (Figure 2.11). We only included the fish that underwent histological analysis when calculating the rate of hermaphrodite occurrence because the presence of small patches of female gametes was not always apparent through visual inspection. Four of the hermaphrodite individuals were captured in the six kilometer stretch directly above the confluence of the Lower Platte River with the Missouri River. Extrapolation to all fish captured in this reach resulted in a 10 percent occurrence rate of hermaphroditism in these six kilometers of the Lower Platte River.

## DISCUSSION

Shovelnose sturgeon in the Lower Platte River closely followed gonad development patterns previously described for lake sturgeon *Acipenser fulvescens* (Bruch et al. 2001) and other shovelnose sturgeon populations (Moos 1978; Colombo 2007; Tripp et al. 2009). All stages described by Colombo (2007) and Tripp et al. (2009) were captured, except for spawning females (FV). The absence of spawning females in our sample was likely due to the short amount of time that a female actually remained in this stage. Despite having similar stages of gonad development, the rate at which shovelnose sturgeon in the Lower Platte River cycle through these stages differs from shovelnose sturgeon in other areas. Shovelnose sturgeon in the Lower Platte River are among the earliest maturing and least frequent spawning shovelnose



sturgeon compared to populations outside of the Platte River (Table 2.4). Shovelnose sturgeon in the Lower Platte River reach maturity at a shorter length than shovelnose sturgeon in the Middle Mississippi River, Upper Mississippi River, and Upper Wabash River. Age at maturity for shovelnose sturgeon is younger in the Lower Platte River than the Middle Mississippi River (Table 2.4). A small, young spawning stock of shovelnose sturgeon in the Lower Platte River may lead to decreased egg production and should raise concerns for the sustainability of the population as the smaller and younger shovelnose sturgeon produced significantly fewer eggs than larger, older individuals.

While differences in reproductive characteristics exist between sturgeon in the Lower Platte River and the Mississippi and Wabash rivers, reproductive characteristics between the Lower Platte River and the unchannelized Missouri River were similar. Size at maturity between the Lower Platte River and the unchannelized Missouri River were similar for both females and males (Table 2.4). Movements of shovelnose sturgeon between the Lower Platte River and the channelized Missouri River are common (J. Hammen 2013, unpublished data), and genetic analysis suggests no differences between shovelnose sturgeon captured in the Lower Platte River and the channelized Missouri River (Heist 2012). It is likely that reproductive traits of shovelnose sturgeon in the channelized Missouri River would be very similar to those of the Platte River because of proximity, connectivity, and genetic similarities between individuals caught in the Lower Platte River and the channelized Missouri River. Both the Lower Platte River and the channelized Missouri River have been highly modified from their natural state, and shovelnose sturgeon in both systems are likely responding to similar environmental and human stressors.

Shifts in life history traits have been linked to reduced intraspecific competition, environmental conditions, and overexploitation (Diana 1983; Godø and Moksness 1987; Spangler et al. 1997; Trippel 1995). Early maturation can be caused by compensatory responses to declining population size and/or by genetic selection (Trippel 1995). Compensatory responses are based on density dependent factors. When mortality is high and stock size becomes low, intraspecific competition decreases. The lower competition could theoretically lead to more food intake per individual and faster growth rates. Individuals are then able to reach maturity at a younger age since they are growing faster (Trippel 1995). Hamel et al. (*in review*) compared shovelnose sturgeon growth across their range and found that individuals in the Lower Platte River were among the fastest growing up to an asymptotic length presumed to be length at maturity. If rate of maturity is a heritable trait, then selection pressures can cause changes in genotype frequencies in a population over time. Selective pressures on shovelnose sturgeon in the Lower Platte River likely also come from harvest and/or harsh environmental conditions. In populations with high mortality, individuals that mature at a large size and older age may have very little, if any, chance to survive and reproduce. In contrast, individuals reaching maturity early may have several opportunities to reproduce before they are removed from the population (Trippel 1995). Although there is no commercial fishery on the Lower Platte River, recreational angling and harvest of shovelnose sturgeon has been documented (Holland and Peters 1994; Latka 1994; Peters and Parham 2008), and harvest of recreationally caught sturgeon has been shown to exceed 73 percent (Holland and Peters 1994). In addition to harvest, shovelnose sturgeon in the Lower Platte River experience dramatic diel fluctuations in discharge and gage height from hydropeaking and irrigation withdrawals. Altered flow regimes have been shown to reduce abundances of aquatic insects (Elser et al. 1977; Gislason 1985), as well as affecting the ability of shovelnose sturgeon to find aquatic insects upon which to forage

(Modde and Schmulbach 1977). Water withdrawals along with local drought conditions in the Lower Platte River have the potential to create conditions where flows are minimal and water temperatures are extreme. In 2012, Nebraska experienced extreme drought, and shovelnose sturgeon were captured or found dead in isolated pools of the Lower Platte River. Daily maximum water temperatures in July, 2012 always exceeded 30°C and exceeded 35°C on several days (USGS gaging station 06805500). Shovelnose sturgeon in the Lower Platte River may be experiencing selective pressures from harsh environmental conditions as well as harvest, causing a shift in reproductive strategy where individuals are maturing earlier.

Fecundity of mature, female shovelnose sturgeon in the Lower Platte River was positively correlated with individual size (length and weight) and age, with weight being the best predictor of fecundity. These results are similar to studies of shovelnose sturgeon in other locations. Shovelnose sturgeon in the Middle Mississippi River (Tripp et al. 2009), Upper Mississippi River (Koch et al. 2009) and the Upper Wabash River (Kennedy et al. 2006) also exhibit a positive correlation between fecundity and fish size, with weight being the best predictor. However, the mean fecundity of female shovelnose sturgeon in the Lower Platte River (16,098; range= 9,307-37,513) was less than reported fecundity from the Middle Mississippi River (29,573; range=5,733-81,842; Tripp et al. 2009), Upper Mississippi River (34,908; range=20,120-66,303; Koch et al. 2009), and the Upper Wabash River (27,523; range=13,241-65,490; Kennedy et al. 2006). Gravid shovelnose sturgeon in the Lower Platte River were, on average, shorter and younger than those from the Middle Mississippi River (Tripp et al. 2009), Upper Mississippi River (Koch et al. 2009), and the Upper Wabash River (Kennedy et al. 2006). These differences in size and age were likely the cause for lower fecundity estimates because fecundity was positively correlated with length (Kennedy et al. 2006, Koch et al. 2009; Tripp et al. 2009; this study) and age (this study).

Variation in egg size from shovelnose sturgeon in the Lower Platte River was not explained by fish size or age. A positive correlation between maternal size and egg size has been well documented in other species such as common carp *Cyprinus carpio* (Zonova 1973; Hulata et al. 1974), Atlantic salmon *Salmo salar* (Kazakov 1981), chum salmon *Oncorhynchus keta* (Beacham and Murray 1985), and dace *Leuciscus leuciscus* (Mann and Mills 1985). However, the life history traits of these species (e.g., earlier maturation, shorter life-expectancy) differ from shovelnose sturgeon. For periodic life-history strategists, such as the shovelnose sturgeon, it may be more advantageous to produce more eggs as opposed to larger eggs (Winemiller and Rose 1992). Gisbert et al. (2000) found that egg size of hatchery-reared Siberian sturgeon was positively correlated to length, body weight, and yolk sac volume of newly hatched larvae. However, these traits did not lead to an increase in larval survival (Gisbert et al. 2000). Periodic strategists are highly migratory, and spawn synchronously. Migration and synchronous spawning allows mature adults to seek the most desirable habitats during a time when environmental conditions are most favorable for larval survival (Winemiller and Rose 1992). An energetic investment in migration is a means by which periodic fishes likely must minimize energy allocated to increasing egg size and could explain the lack of relation in body size to egg size.

Reproductive potential of gravid, female shovelnose sturgeon in the Lower Platte River across both size and age ranges was not equal. Fecundity of gravid female shovelnose sturgeon in the Lower Platte River was positively correlated with weight, length, and age. There is an existing assumption in the fisheries literature that spawning stock biomass (SSB) adequately represents reproductive potential. Spawning stock biomass is the cumulative biomass of mature females in the stock. Often SSB is calculated by summing the products of the frequency and mean weight of mature females in each age-group (Goodyear 1993). However, in many

cases SSB assumes that a given weight of spawning biomass will have an equal likelihood of generating the same level of recruitment. That is, 100 kg of low condition or young fish would produce the same number of recruits as 100 kg of old fish or fish in good condition (Trippel 1999). The difference in reproductive potential among spawning biomass is why the term SSB is so potentially problematic (Trippel 1999). To truly understand the potential of a stock, mature individuals must be partitioned into groups (e.g., size, age, condition) to test the contribution of future recruitment from each group.

Male and female shovelnose sturgeon in the Lower Platte River have reproductive cycles of different length and complexity. Approximately one-third of males above the minimum length at maturity were in spawning condition each year, whereas only one-fourth to one-sixth of females larger than the minimum length at maturity were in spawning condition. However, a prolonged reproductive cycle in females may be expected. Ovaries comprise a much larger percent of the total body weight (14%) than testes (3%) and thus require a greater energetic investment. This prolonged reproductive cycle in females allows for reproductive investment to span several years, providing opportunities for a portion of the population that is in reproductive condition to successfully reproduce if favorable spawning and recruitment conditions exist (Warner and Chesson 1985; Winemiller 2005). This reproductive strategy requires that the species be long-lived, and have many spawning events to compensate for years when favorable conditions may not exist (Warner and Chesson 1985), as is the case with the shovelnose sturgeon.

Protracted or bimodal reproduction may be a life-history strategy used when there is high variation in environmental factors, resulting in differential growth and survival across life stages (Garvey et al. 2002). Early hatched larvae reach greater sizes by fall compared to larvae

hatched later in the year, but early hatched larvae are also then subjected to variable environmental conditions that may reduce survival. For example, shovelnose sturgeon hatched in the Lower Platte River during spring have to endure harsh summer conditions including low water levels, extreme high water temperatures, and drastic diel changes in water levels from power generation and irrigation withdrawals while they are drifting through the Lower Platte River. Conversely, shovelnose sturgeon hatched in the Lower Platte River during the fall would be relatively smaller than those hatched in the spring; yet, they would not have been subjected to the extreme summer conditions. Shovelnose sturgeon reproduction in the Lower Platte River appears to be bimodal. At a population level, a bimodal spawn would allocate spawning efforts across two time periods and could improve overall recruitment success if spawning habitat is limiting. That is, a preferred spawning site could be used by one mature female in the spring, and the same site could be used by another mature female in the fall. Alternatively, only one of those females would be able to use the preferred spawning site, while the other was forced to use a less desirable site, if the same two mature females were to spawn in the spring. We found the highest proportion of reproductively mature individuals in the spring (March-May) and the fall (September-October) in both years of this study. The highest proportions of reproductively mature individuals coincided with water temperatures that were within or near the 16.9 to 20.5°C range that shovelnose sturgeon are thought to spawn (Keenlyne 1997). Tripp et al. (2009) reported a similar bimodal spawn in shovelnose sturgeon in the Middle Mississippi River. Spawning-ready (males producing milt and females with eggs in spawning condition) shovelnose sturgeon were captured in the fall, as well as one age-0 sturgeon that was most likely spawned in September (Tripp et al. 2009). Other studies have documented fall spawning in Atlantic sturgeon *Acipenser oxyrinchus* (Collins et al. 2000) and several Eurasian species (Berg 1959). The magnitude of fall spawning as well as the extent to which fall spawning contributes to the

population in the Lower Platte River still needs examined. Efforts should be focused on capturing age-0 sturgeon to determine spawning time as well as to compare the relative magnitude and egg viability of spring versus fall spawned individuals. Differences in relative abundance and survival between spring and fall spawned progeny would provide insight into the overall contribution to the population from both spawning periods.

A total of five hermaphroditic fish were identified throughout this study, resulting in a 2.2% rate of occurrence. This intersex rate is similar to the 1.9% (Tripp 2004) and 2% (Colombo et al. 2007) reported in the Middle Mississippi River and the 1.6% (Moos 1978) reported in the Missouri River. Although the overall occurrence of intersex fish in the Lower Platte River is similar to reports from previous studies, most of the occurrences were located in a six kilometer stretch of river directly above the Lower Platte River and Missouri River confluence. The six kilometer stretch directly above the Missouri River confluence is an area with a high relative abundance of shovelnose sturgeon (J. Hammen 2013, unpublished data). A high rate of occurrence of hermaphrodites in an area with a high abundance has more potential for adverse population effects than if the same rate occurred in an area with low concentrations. That is, 10 percent occurrence of hermaphroditism in high abundance areas (e.g., six kilometer stretch above Missouri River confluence) results in more individual hermaphrodites within the Lower Platte River than if the same 10 percent occurrence rate was in an area of low abundance (e.g., the Platte River near Columbus, Nebraska). Schwarz et al. (2006) reported adverse reproductive conditions of shovelnose sturgeon captured throughout the entire Lower Platte River including abnormal vitellogenin concentrations and estradiol/testosterone ratios in blood plasma. Factors that Schwarz et al. (2006) hypothesized could be responsible for the reproductive conditions included high water temperatures and exposure to environmental contaminants because

polychlorinated biphenyls, selenium, and atrazine were all detected at concentrations of concern in shovelnose sturgeon collected in the Lower Platte River.

This study is the first to describe reproductive strategies of shovelnose sturgeon in the Lower Platte River including length and age at maturity, fecundity, spawning frequency, and spawning season. Shovelnose sturgeon in the Lower Platte River exhibit earlier maturity and less frequent spawning compared to populations elsewhere. These comparisons demonstrate that life-history strategies of the same species can be shaped by location and validate the need for location-specific studies defining the reproductive cycles of shovelnose sturgeon. Life-history characteristics specific to Lower Platte River shovelnose sturgeon can be used to enhance population assessment models and guide management decisions. However, information gaps still exist. Future research should focus on determining the contribution of spring and fall spawning to the population and determining if specific, suitable spawning areas exist. This information would allow for spawning periods and locations to be protected by setting harvest seasons and/or restrictive harvest zones to improve reproductive success.

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Table 2.1. Stages of gonadal development for shovelnose sturgeon (adapted from Tripp et al. 2009 and Colombo et al. 2007)

Sex	Stage	Gonad Description	Histology Description
Female	Fv	Virgin female; small well-ordered ovarian folds with a small amount of fat	Ovaries containing nests of oogonia, some primary oocytes may be seen in the follicular epithelium.
	FI	Ovarian folds with a large amount of fat	Many small, primary oocytes present that have migrated to the walls of the ovigerous lamellae, nuclei of these oocytes are centrally located.
	FII	Small white to yellow oocytes	Yolk formation begins, with two distinct zones, the internal zone containing large lipid vacuoles and the external zone with small yolk vacuoles.
	FIII	Yellow to green eggs	Presence of large central nucleus, cellular matrix with micro-and macroplatelets distributed in a two-layer fashion, many striations apparent in the zona radiata, producing a columnar appearance.
	FIV	Black eggs	Melanosomes present inside the oocyte cell membrane, germinal vesicle migrate to the animal hemisphere.
	FV	Spawning female	
Male	FVI	Spent or recovering female, translucent ovary with atretic oocytes	Presence of both atretic and developing oogonia.
	Mv	Virgin male; pink ribbon-like testis embedded in a small amount of testicular fat	Seminiferous tubules devoid of mature Spermatozoa, spermatagonia embedded within seminiferous tubules.
	MI	Yellow tubular testis in a large amount of fat	Appearance similar to Mv males, numerous spermatagonia dispersed in homogenous fashion.
	MII	Large pink testis in a reduced amount of fat	Presence of mature spermatozoa packed into seminiferous tubules, spermatozoon with elongated head.
	MIII	Spent male; compressed red-pink testis	

Table 2.2. Sex and stage specific fork length (FL) and age ranges for shovelnose sturgeon captured in the Lower Platte River in 2011 and 2012.

sex	stage	FL (mm)				Age (years)		
		minimum	maximum	mean	SE	minimum	maximum	median
Female	Fv	377	532	465	13.41	3	10	7.0
	FI	440	703	538	7.66	4	14	9.0
	FII	435	667	579	8.35	6	13	10.0
	FIII	486	673	598	12.03	7	16	10.0
	FIV	486	703	594	8.95	8	16	10.5
	FVI	522	695	604	6.13	7	15	11.0
Male	Mv	439	645	547	6.37	4	14	10.0
	MI	447	664	533	6.71	5	15	9.0
	MII	453	725	566	9.87	6	14	9.0
	MIII	498	635	565	9.87	7	15	10.0



Table 2.3. Percent of shovelnose sturgeon catch that was larger than the minimum length at maturity and had fully mature sperm (MII) or eggs (FIV).

Sex	Year	Total above minimum length at maturity	Total with mature gametes	Percent with mature gametes
Female	2011	42	11	26
	2012	130	19	15
Male	2011	50	15	30
	2012	150	49	35

Table 2.4. Reproductive cycle comparisons of minimum fork length and age at maturity, spawning cycle, and spawning season between the Lower Platte River and the unchannelized Missouri River (Moos 1978), Middle Mississippi River (Tripp et al. 2009), Upper Mississippi River (Koch et al. 2009), and the Upper Wabash River (Kennedy et al. 2006).

Location	Sex	FL at Maturity (mm)	Age at Maturity (years)	Spawning Frequency (years)	Spawning season
Lower Platte River	Female	449	6	4-6	March-May and September-October
	Male	453	6	3	
Unchannelized Missouri River	Female	472	-	2-3	May - June
	Male	442	-	1-2	
Middle Mississippi River	Female	570	9	3-4	March-April and October
	Male	531	8	2	
Upper Mississippi River	Female	570	6	-	-
Upper Wabash River	Female	570	6	2-3	April-May

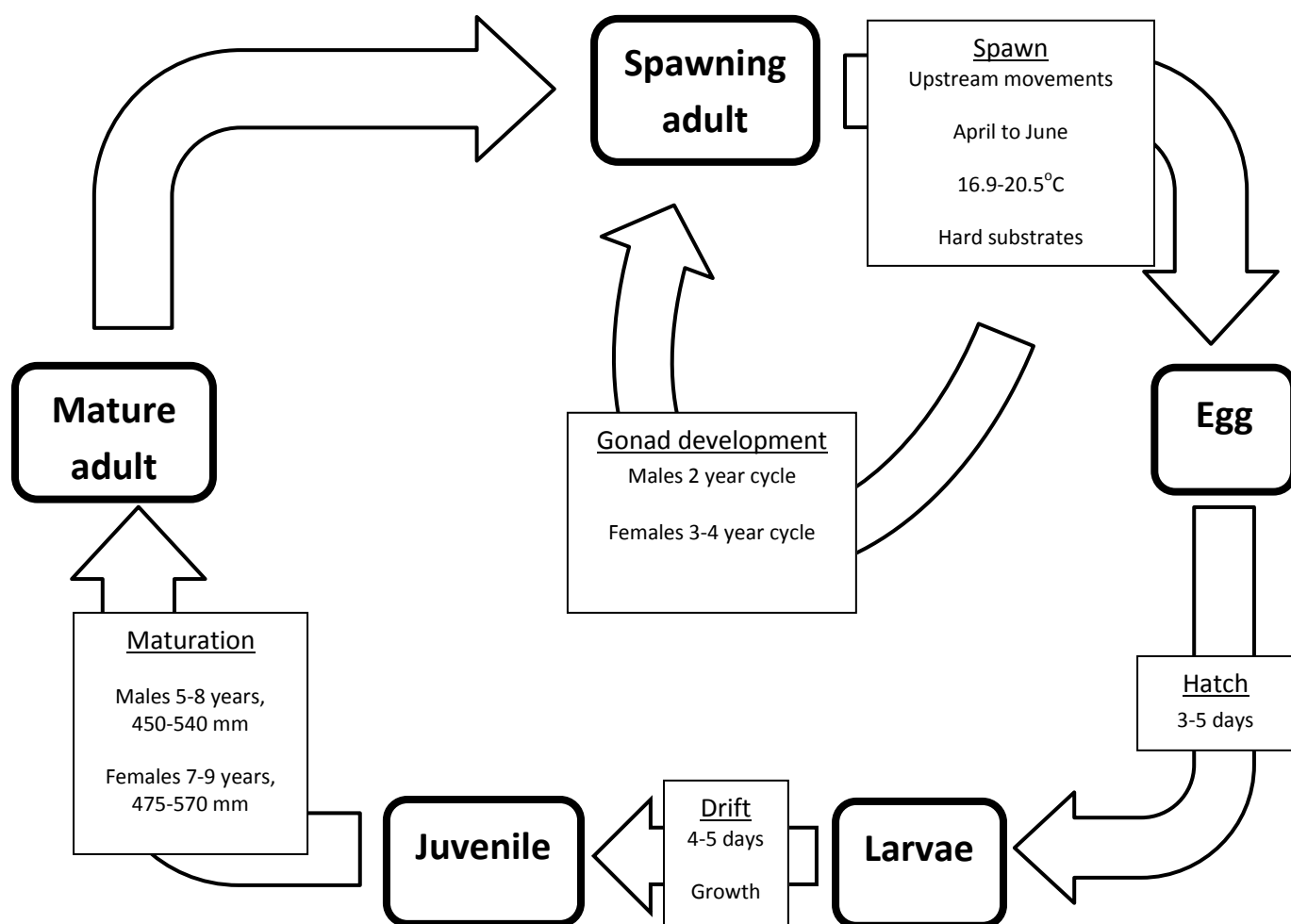


Figure 2.1: Conceptual diagram of shovelnose sturgeon life history as is currently supported in the literature.

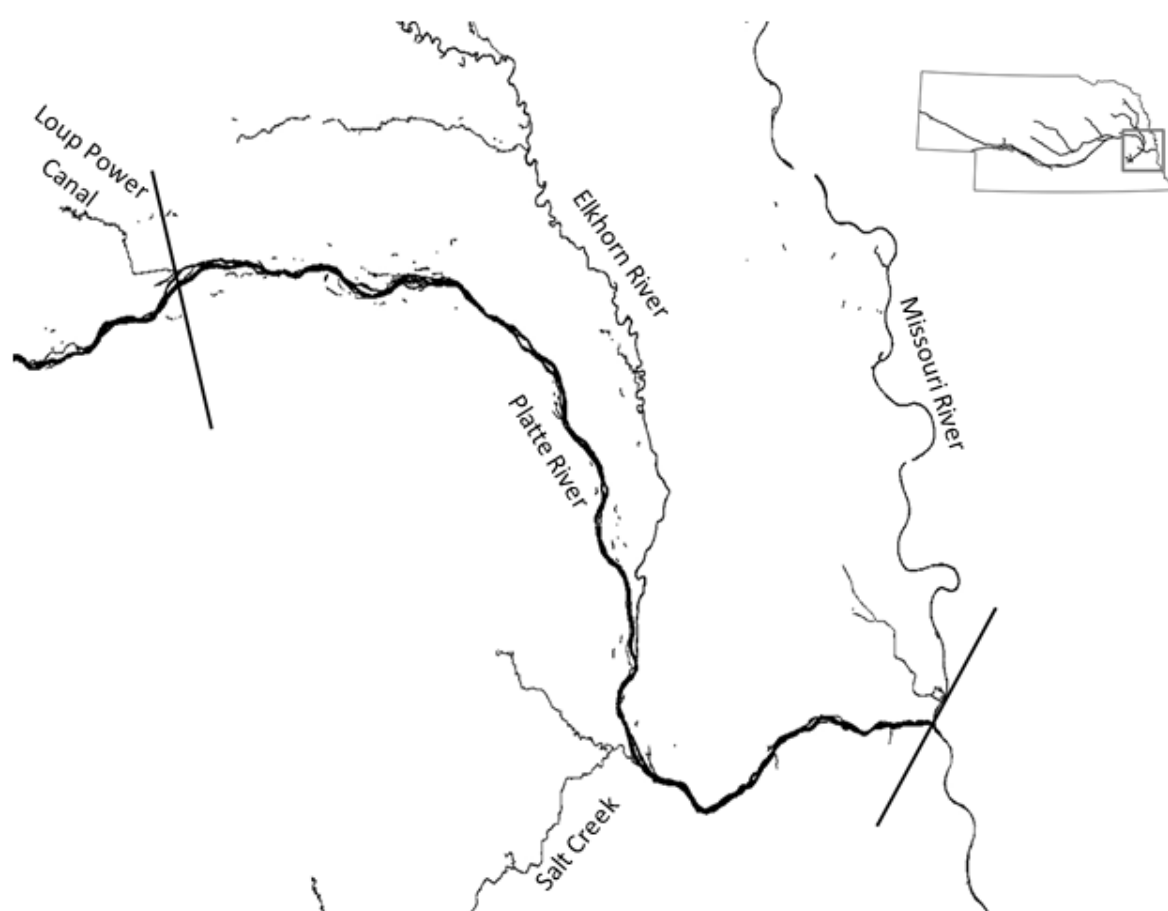


Figure 2.2. Map of Lower Platte River extending between the confluence with the Missouri River upstream to the confluence with the Loup River. Sampling was conducted in the Platte River between the nearly vertical solid lines.

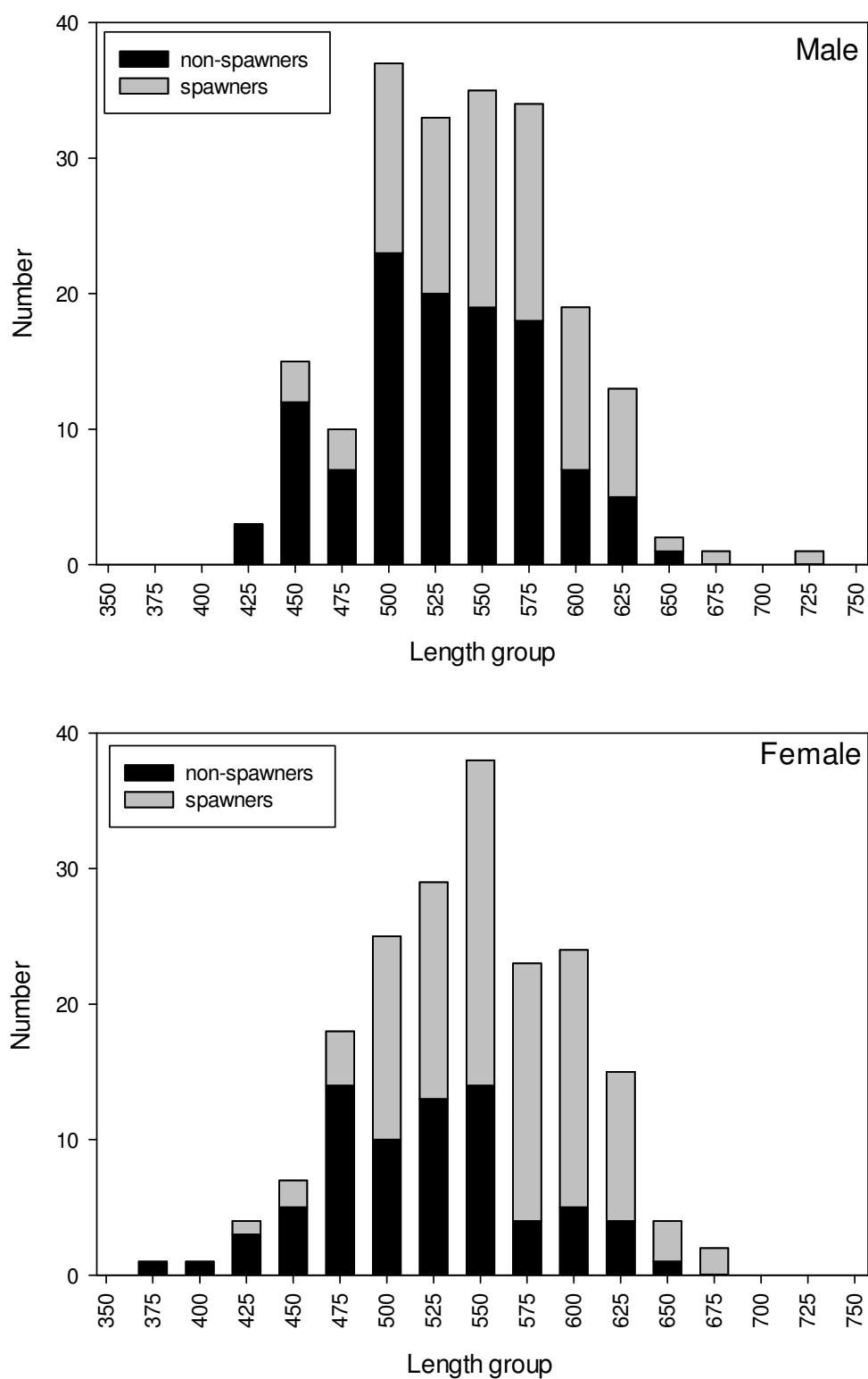


Figure 2.3. Length-frequency distribution for shovelnose sturgeon captured in the Lower Platte River during 2011 and 2012. Black bars are non-spawning fish, and grey bars are spawning fish.

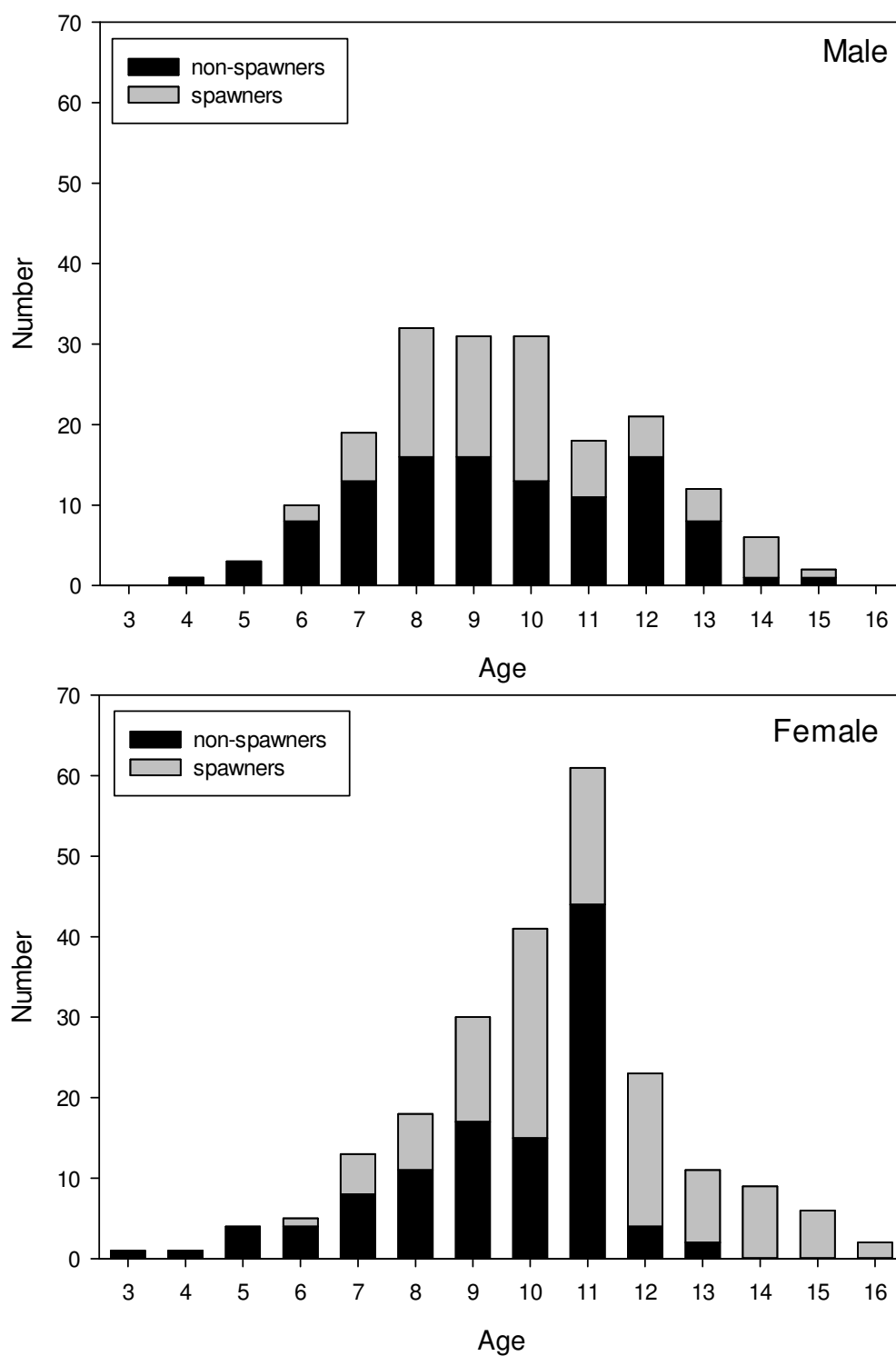


Figure 2.4. Age-frequency distribution for shovelnose sturgeon captured in the Lower Platte River during 2011 and 2012. Black bars are non-spawning fish, and grey bars are spawning fish.

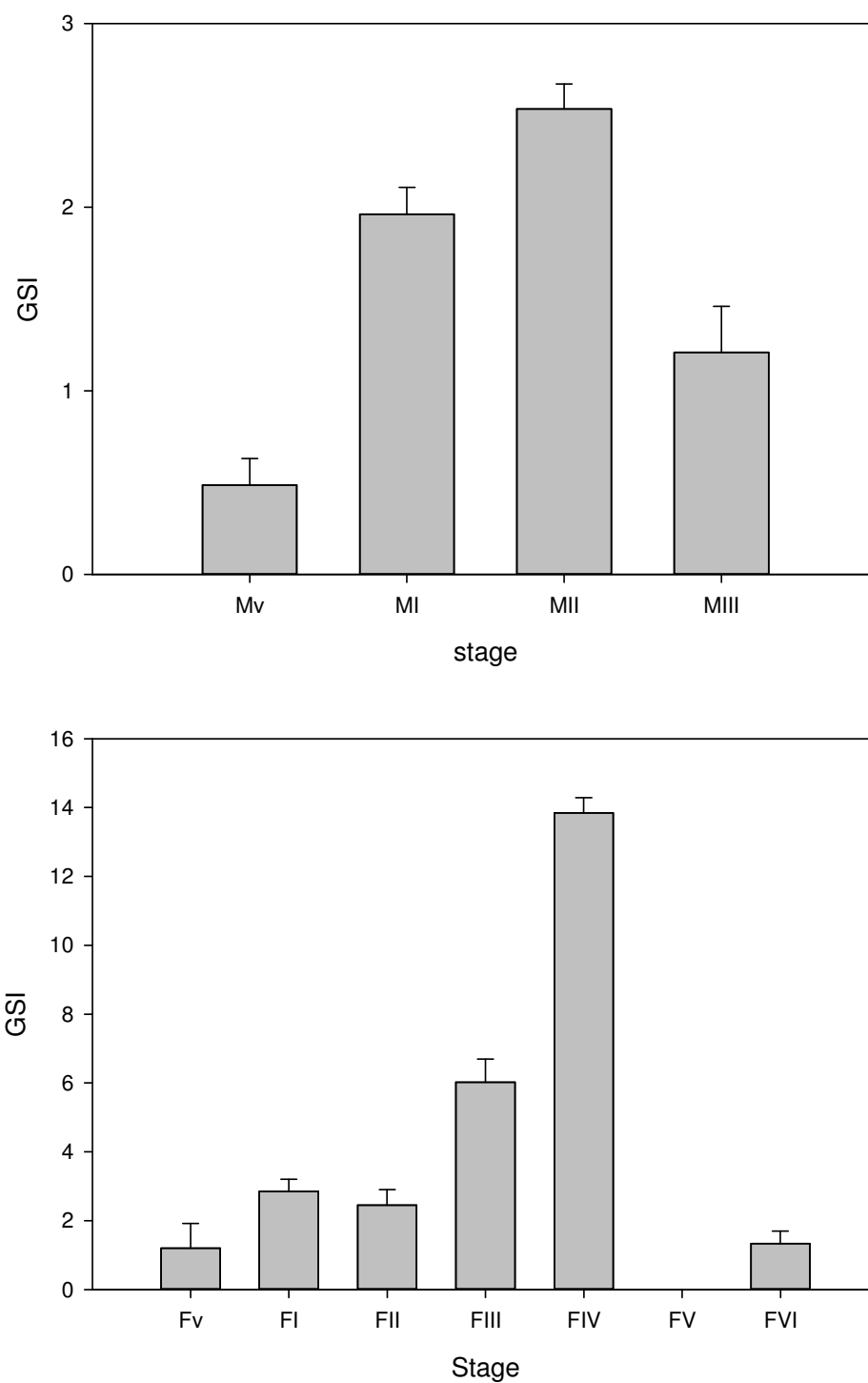


Figure 2.5. Mean  $\pm$  SE gonadosomatic index (GSI) for each stage of the male and female shovelnose sturgeon gonadal development in the Lower Platte River during 2011 and 2012. Different letters represent significantly different means at  $\alpha=0.05$ .

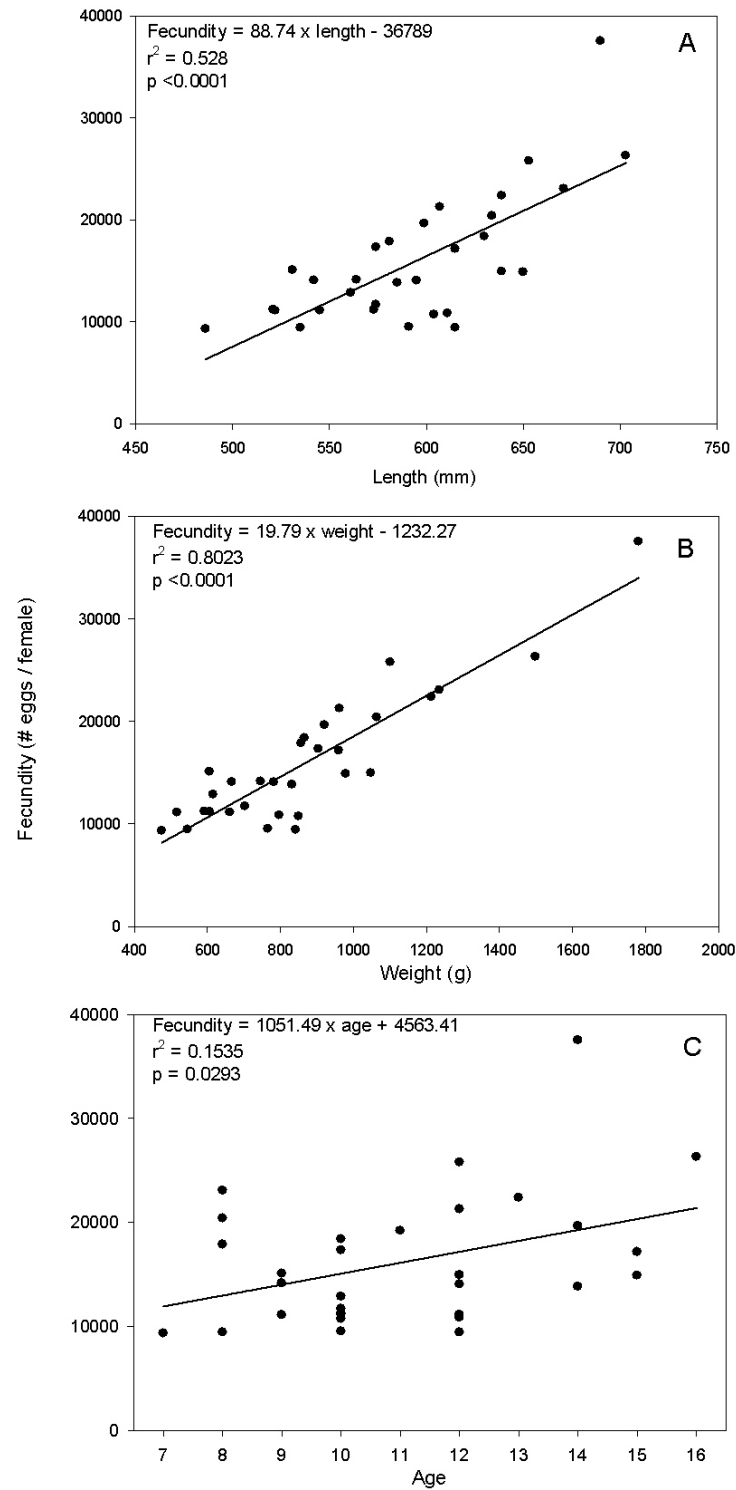


Figure 2.6. Relations between fecundity of stage FIV female shovelnose sturgeon and fork length (A), weight (B), and age (C). The lines indicate the predictive fecundity equations.



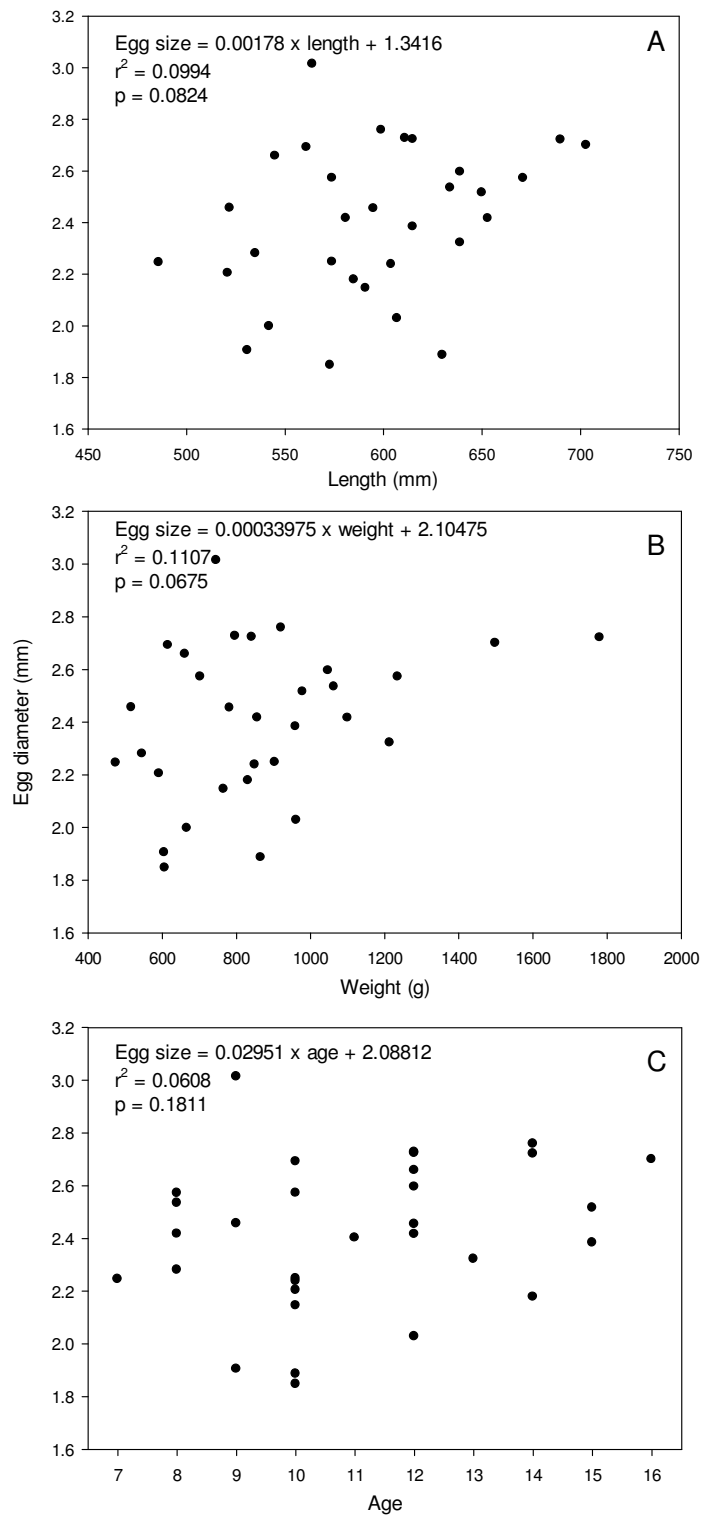


Figure 2.7. Relations between egg size of stage FIV female shovelnose sturgeon and fork length (A), weight (B), and age (C).

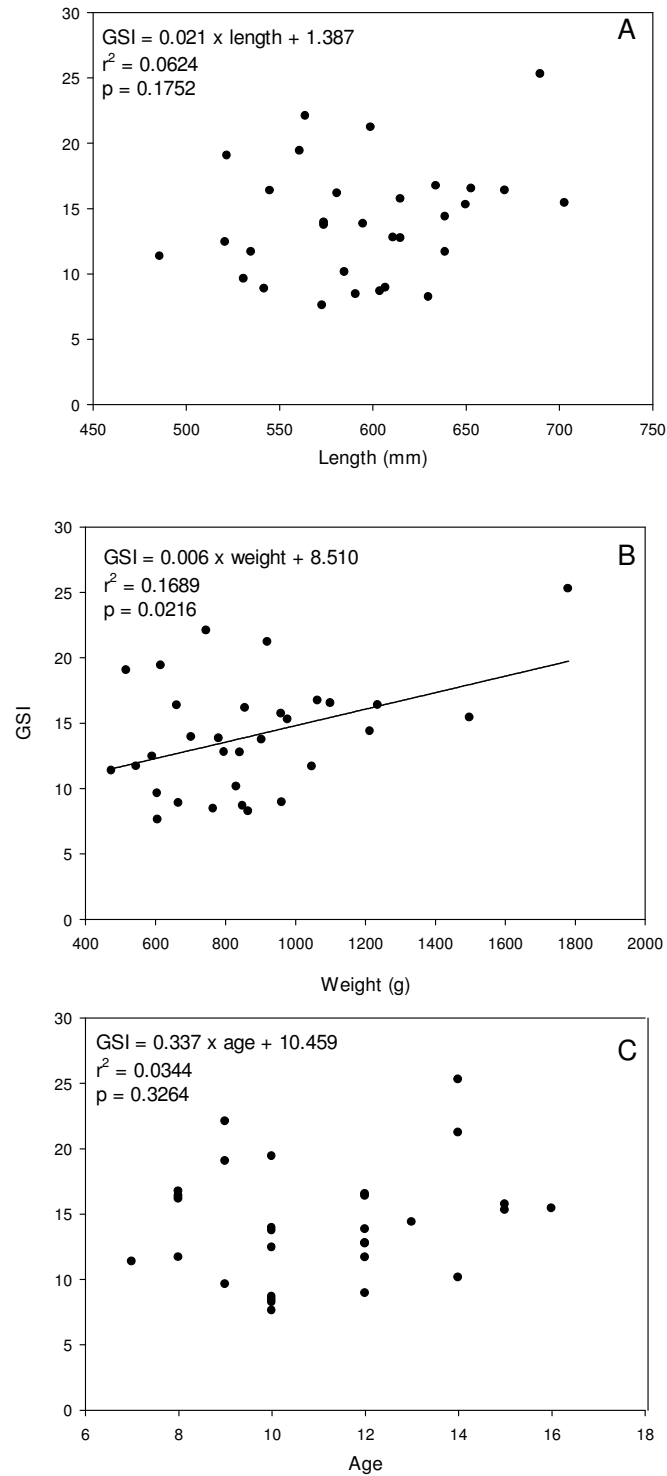


Figure 2.8. Relation between gonadosomatic index (GSI) of stage FIV female shovelnose sturgeon and fork length (A), weight (B), and age (C). The line indicates the predictive fecundity equations.

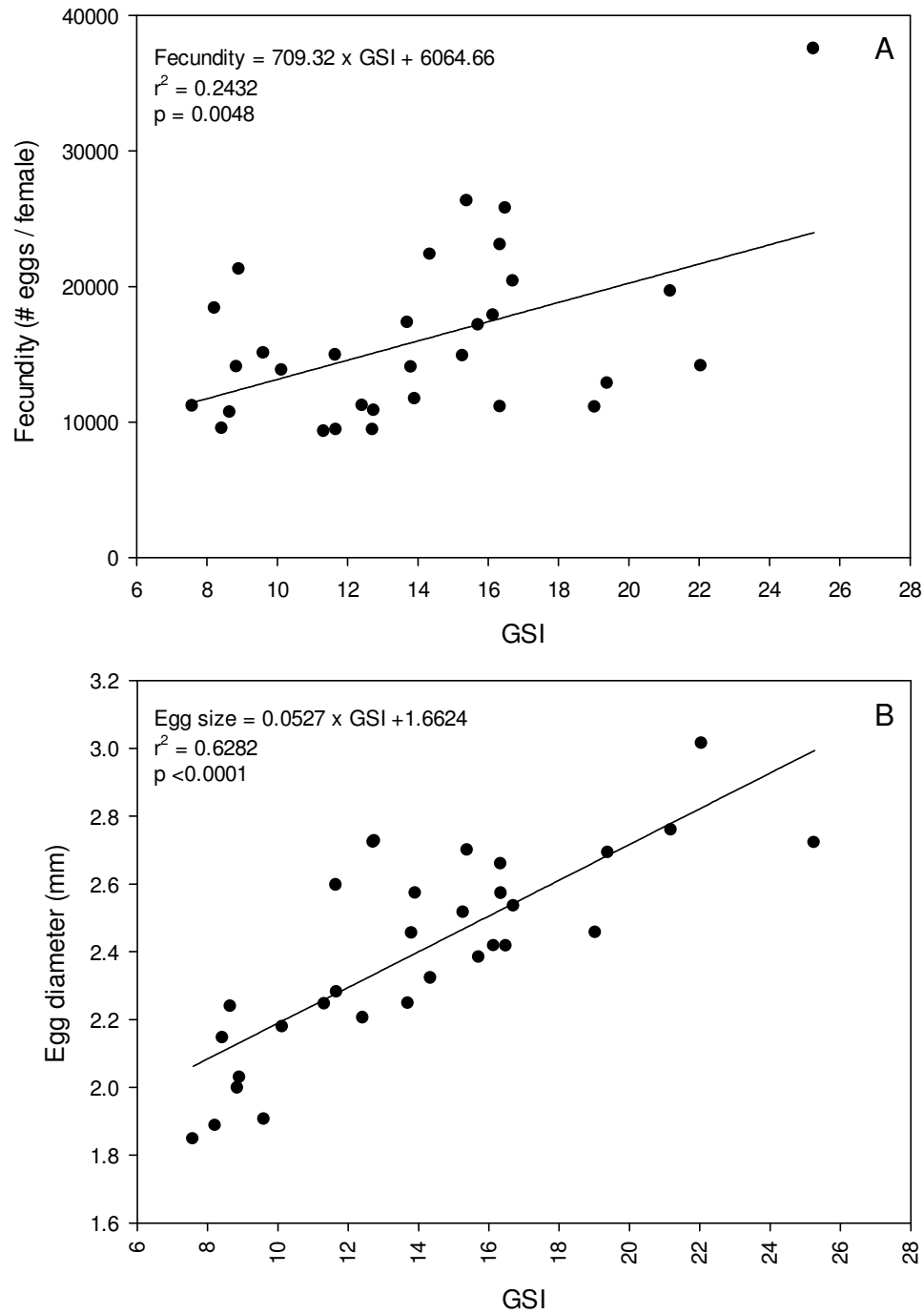


Figure 2.9. Relation between fecundity (A) and egg size (B) of stage FIV female shovelnose sturgeon and gonadosomatic index (GSI). The lines indicate the predictive fecundity and egg size equations.

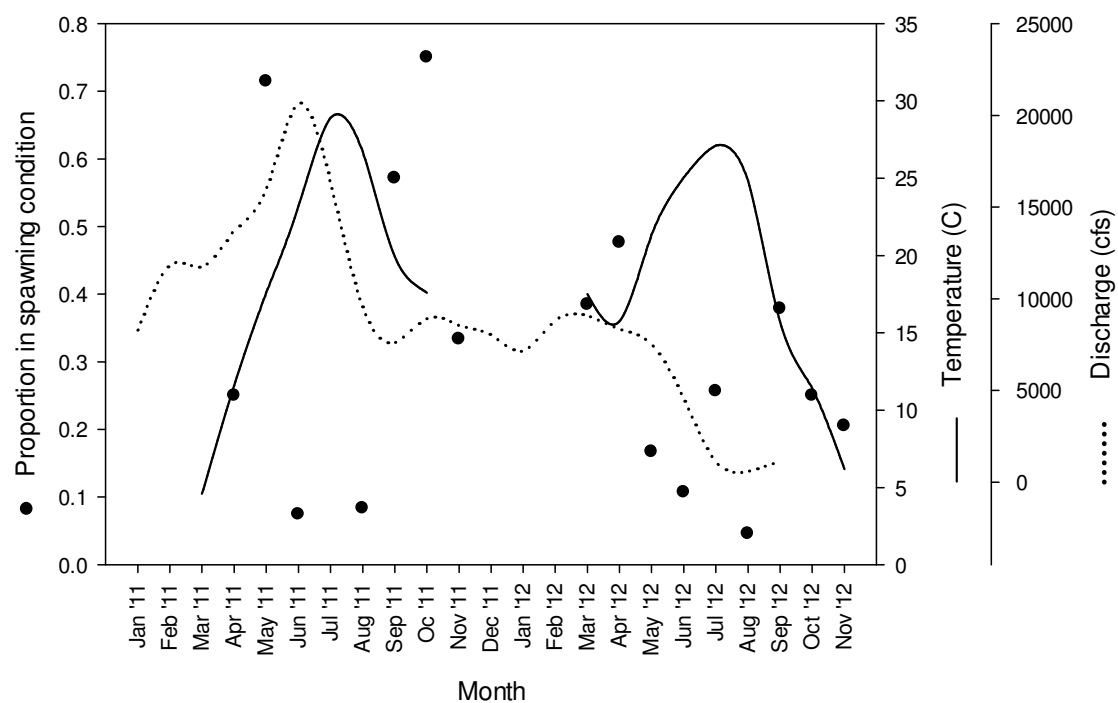


Figure 2.10. Proportion of reproductively mature males and females (MII and FIV; black circles) plotted with discharge (dotted line) and water temperature (black line). Discharge and temperature are monthly averages from the Louisville, NE USGS gaging station (Gage – 06805500). Mean monthly water temperature recorded while sampling was used if the gaging station did not have temperature history for a given month.

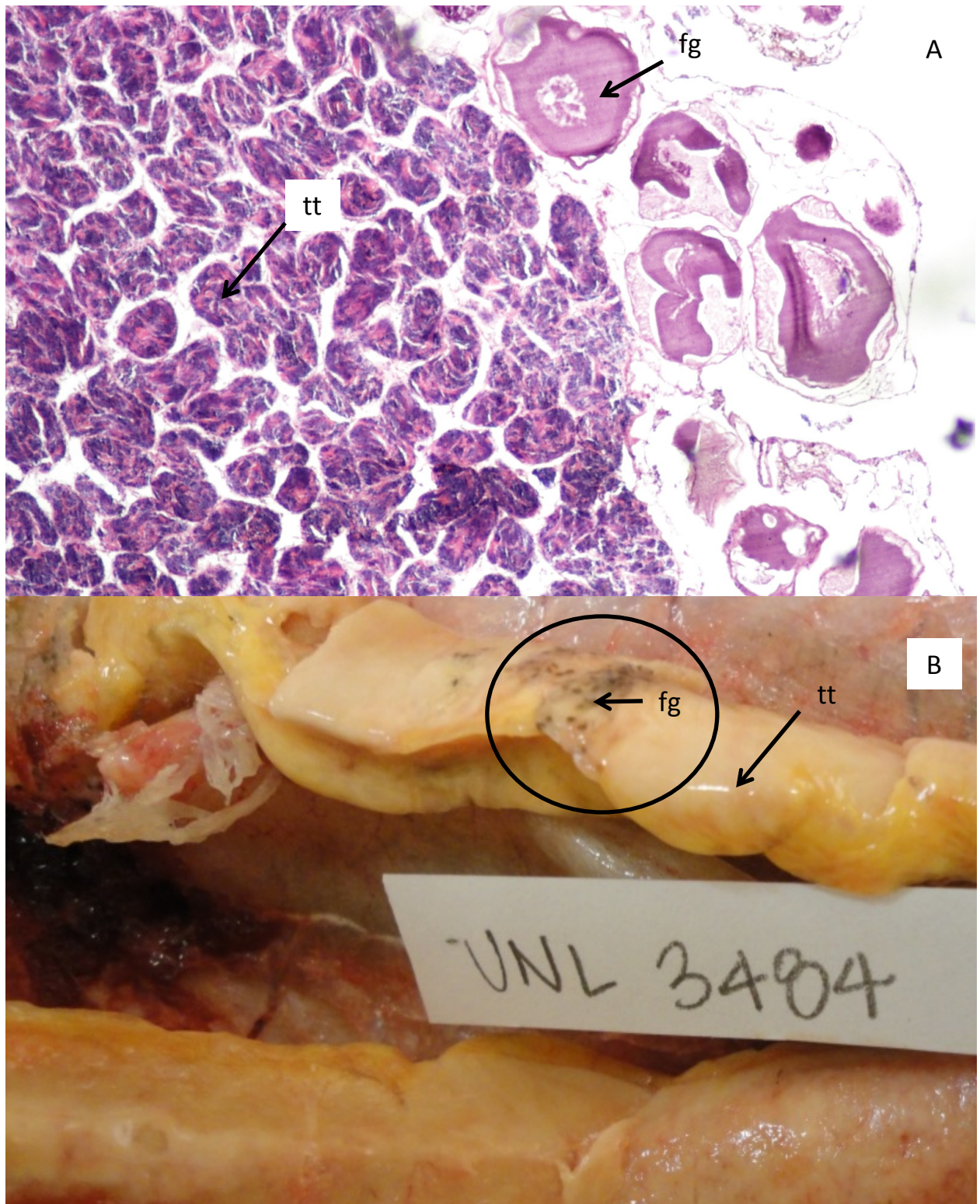


Figure 2.11. Histological (A) and whole gonad (B) images of hermaphrodite shovelnose sturgeon captured in the Lower Platte River. Area within black circle indicates female gametes (fg) imbedded within testicular tissue (tt).

### **CHAPTER 3: VALIDATION OF ANNULI FORMATION IN PECTORAL FIN RAYS FROM SHOVELNOSE STURGEON IN THE LOWER PLATTE RIVER, NEBRASKA.**

#### **ABSTRACT**

Fish age is commonly estimated by counting bands on calcified structures. Age estimates are used to calculate population dynamics information such as growth, mortality, age-frequencies, and recruitment. Pectoral fin rays are the frequently used structure to age sturgeon species, yet very few studies have been done to validate annuli formation. We collected shovelnose sturgeon monthly from the Lower Platte River during 2011 and 2012, and the leading, left pectoral fin ray from each fish captured was removed. We used marginal increment analysis to assess the validity of using pectoral fin rays from shovelnose sturgeon in the Lower Platte River as indicators of deposition of annular marks. There appears to be two complete cycles of increasing and decreasing increment values between March and November within each year. Mean marginal increments showed some slight trends with peaks in March, July, and October followed by a decrease in increment length during April, September, and November. However, mean marginal increments did not differ ( $p>0.05$ ) between months in either year. These results suggest no discernible pattern in growth ring deposition for shovelnose sturgeon in the Lower Platte River that likely lead to biased age estimates. Inaccuracies in age assignment can lead to errors when calculating population dynamic parameters as well as misguided management decisions. We recommend that alternative methods for aging shovelnose sturgeon be explored.

## INTRODUCTION

Osseochronometry, the estimation of lapsed time from calcified structures, has been widely used in fisheries science for over 250 years (Casselman 1987). Age estimation of fish from their calcified structures involves systematic interpretation, usually based on optical appearance, of whole, part, or sections of structures. Zones that are optically different based on their relative translucency are thought to be associated with a cessation or reduction in somatic growth. These zones can be interpreted as time passed (i.e., days, years), if the calcified tissue is deposited on a known temporal cycle (Casselman 1987). Calcified structures used for aging sturgeon species include fin rays, opercles, clavicles, cleithra, medial nuchals, otoliths, and dorsal scutes. Fin rays are the most commonly used of these structures to estimate age in sturgeon (Brennan and Cailliet, 1989), yet the validity of age estimates from fin rays has rarely been examined. The few studies that have attempted to validate age estimation techniques for sturgeon are location and species specific, and the results should not be extrapolated to other sturgeon species in different locations.

Accurate age data are essential for proper management of a fishery, as inaccurate age data can lead to estimation errors in growth, mortality, age frequencies, and year-class assignment (Isely & Grabowski 2007). Beamish and McFarlane (1983) emphasized the importance of validating age estimation procedures and indicated that many researchers neglect validating their techniques despite the importance of accurate age determination. Many sturgeon studies have operated under the assumption that a set of opaque and translucent bands on fin ray cross sections represented one year of life. However, we were only able to find a handful of studies that attempted to validate pectoral fin ray age estimates in sturgeon (Rossiter et al. 1995; Bruch et al. 2009; Rien & Beamesderfer 1994; Koch et al. 2011), and only one study specifically on shovelnose sturgeon (Whiteman et al. 2004). Despite the

wide use of age data, very few studies have attempted to validate annulus formation for shovelnose sturgeon.

One way to validate annulus formation in shovelnose sturgeon is through marginal increment analysis. Marginal increment analysis is a technique that examines the formation of opaque and translucent bands in calcified structures. The outermost increment is measured and plotted against time. If the increments are formed on a yearly cycle, then the average state of completion of the outermost increment should display a yearly, sinusoidal cycle when plotted against time and can be used for estimating age (Campana 2001) (Figure 3.1). Whiteman et al. (2004) used marginal increment analysis and determined that most shovelnose sturgeon in the Missouri River, Missouri formed opaque bands in the summer months (i.e., July). However, variation in annuli deposition timing and the presence of second or false annuli outside of the summer months were present. Additional validation across the shovelnose sturgeon range is needed; therefore, we examined both the timing and the periodicity of annulus formation in fin rays. Our specific objective was to assess the current technique used to estimate age of shovelnose sturgeon in the Lower Platte River by identifying temporal patterns of annulus formation in pectoral fin rays using marginal increment analysis.

#### STUDY SITE

The Platte River is an alluvial, sand-bottomed, braided river system formed by the confluence of the North Platte and South Platte rivers. The Platte River drains over 230,000 km<sup>2</sup> from the east slope of the Rocky Mountains in Colorado and Wyoming across the entire state of Nebraska until it drains into the Missouri River. A dominant characteristic of the Platte River is that it is a dynamic system with shifting sand that creates and moves sand bars, alters channel



dimensions, and continually changes habitat quantity, quality and availability (Galat 2005). The entire system has been affected by anthropogenic alterations in the form of power generation structures and irrigation diversions. The Lower Platte River, defined as the stretch between the Loup River confluence with the Platte River near Columbus, Nebraska to the confluence with the Missouri River near Plattsmouth, Nebraska (Figure 3.2), is characterized by continuous but variable flows, with base flows coming from the Loup and Elkhorn Rivers, and the Loup River Power Canal (Holland and Peters 1989; Galat 2005). The Loup River Power Canal causes drastic downstream, diel changes in water depth, water velocity, and cover availability due to hydropeaking to meet electricity demands (Holland and Peters 1989).

## METHODS

Shovelnose sturgeon were captured from the Lower Platte River (Figure 3.2) from March to November during 2011 and 2012. Fish were captured using drifted trammel nets (38.1-m long with 2.5-cm and 20.3-cm inner and outer bar mesh) and stationary trotlines (32-m long with 20 baited hooks). The leading edge of the left pectoral fin ray was removed from each captured shovelnose sturgeon and was later used for marginal increment measurements. The fin rays were prepared using methods outlined in Koch and Quist (2007) where the fin ray is embedded in an epoxy-resin solution and then cross-sectioned once the epoxy has hardened. Cross-sections were cut using a Buehler IsoMet precisions saw; then mounted on a glass slide, using Cytoseal mounting medium; and photographed using a high resolution digital camera. The distance from the outermost opaque band to the outer edge of each fin ray was measured at five locations proximal to each other in the ventral, posterior lobe of the ray (Figure 3.3). This location was chosen as it was located along the transect of the fin ray most commonly used for

age estimation and the location could be standardized such that measures could be consistent across individuals. The average of these five measurements was calculated and reported as the marginal increment. Average marginal increment was plotted against month to validate if opaque bands were formed once annually and to determine when the annulus was formed. Analysis of variance (ANOVA) with a Tukey-Kramer correction for multiple comparisons was used to test for differences in margin increments among months.

## RESULTS

We collected a total of 418 fin rays from shovelnose sturgeon (377 to 725 mm fork length) in the Lower Platte River, 136 in 2011 and 282 in 2012. Marginal increments ranged from 0 to 255.22  $\mu\text{m}$ . Through visual inspection of the marginal increments, it appeared there were two complete cycles of increasing and decreasing increment values between March and November within each year (Figure 3.4). Marginal increment distances peaked in the months of March, July, and October. Peaks were followed by a decrease in increment length during April, September, and November (Figure 3.4). However there were no differences in mean marginal increments between months in either year ( $p>0.05$ ). Marginal increment distance was highly variable within months, and March 2011 was the only month that did not contain at least one individual where there was no increment between the last opaque band and the fin ray edge. There was also high variability among increment measurements on the same fin ray. The average range of increment measurements on the same fin ray was  $13.18 \mu\text{m} \pm 0.73 \mu\text{m}$  (mean  $\pm$  SE), with the largest range being 157.70  $\mu\text{m}$ .

## DISCUSSION

The mean marginal increment for shovelnose sturgeon fin rays in the Lower Platte River did not exhibit a yearly sinusoidal pattern as would be expected if one pair of opaque and translucent bands corresponded to a complete year of growth (i.e., annuli). Several previous studies have assessed the appropriateness of using fin rays from sturgeon to estimate age. Whiteman et al. (2004) found that an opaque band was laid down in summer months for most shovelnose sturgeon in the Missouri River, but advised caution in using fin rays as there was variation in the timing of annuli deposition and because there was often a second or false annulus outside of the summer months (Whiteman et al. 2004). Rien and Beamesderfer (1994) aged white sturgeon *Acipenser transmontanus* using fin ray cross-sections and reported that over 70 percent of individuals less than 600 mm in the Columbia River were assigned the correct age based on recaptures of individuals with previous oxytetracycline (OTC) marks. However, the accuracy of white sturgeon age estimates decreased as fish length increased, and less than 60 percent of individuals over 1,000 mm were accurately aged (Rien and Beamesderfer 1994). Similarly, Hamel et al. (*in review*) assessed ages estimates from fin rays of known-age pallid sturgeon and found that exact accuracy compared to the true age was only 13%, and increased to 43% within one year and 72% within two years of the true age. There are several possible explanations why the band formation from shovelnose sturgeon in the Lower Platte River did not follow a yearly sinusoidal curve. Bands on fin rays may not represent body growth, or bands may represent body growth, but body growth does not follow the predicted sinusoidal curve on an annual cycle. If fin ray banding from shovelnose sturgeon in the Lower Platte River does not correlate to body growth, then fin rays are not a structure that should be used for age estimates. However, assuming the distances reflect actual periodicity, marginal increment lengths from shovelnose sturgeon exhibited very similar yearly trends between 2011 and 2012.

Each year had two complete cycles of increasing and decreasing increment lengths, and the peaks of the cycle (largest increments) were in the same months each year. Shovelnose sturgeon in the Lower Platte River may actually form three pairs of bands annually in some cases. Causes for these multiple bands are not yet known, but if multiple pairs of fin ray bands are formed on a predictable annual cycle, then fin rays may be a suitable structure for age estimation. However, much more work is needed to determine if our interpretation of age would need to change so that multiple pairs of bands equaled one year. Age estimates of shovelnose sturgeon in the Lower Platte River are likely inaccurate when assuming that one pair of translucent and opaque fin ray bands equates to one year.

We used marginal increment analysis in an attempt to validate that a set of bands form an annulus, yet some restrictions are associated with this method. Marginal increment analysis is best suited for young, fast-growing fish, where the marginal increment is most easily discerned. Results may be misleading when marginal increment is used to validate annuli formation in slow-growing, long-lived species because the margin increment is often difficult to identify during periods of slow growth (Campana 2001). Woodland (2005) identified several common sources of aging error from fin rays of shortnose sturgeon *Acipenser brevirostrum* that may also lead to inaccurate marginal increment measurements including: resorption of calcified material, inclusion of secondary rays with posterior lobes, inconsistent annulus width, and crowding of annuli near the edge of the fin ray. Inconsistent annulus width and crowding of annuli were most present in the fin rays we viewed, and likely contributed to the large variation between increment measurements on the same fin ray. Investigators have speculated that crowding of annuli can occur when energy is diverted from somatic growth to gonad development (Cuerrier 1951). Fish of all ages, lengths, and sexes were combined in this study when comparing average marginal increment between months. Our sample size did not allow

for monthly comparisons between fish of similar length and sex and does not account for differences in marginal increment due to life-cycle stage an individual was in at time of capture. Despite these limitations, marginal increment has been used previously to investigate annuli formation in shovelnose sturgeon (Whiteman et al. 2004), and the technique provides at the very least a preliminary assessment of age estimates from fin rays. Alternative methods (e.g., mark-recapture studies, rearing known-age fish) require a large investment of time and effort that is beyond the scope of many short term studies, especially for long-lived fish such as sturgeon. Therefore, marginal increment analysis can provide a technique to validate annulus formation when time and/or effort are limited.

Age at maturity (Chapter 2) and maximum age (J. Hammen 2013, unpublished data) for shovelnose sturgeon in the Lower Platte River was derived using age estimates from pectoral fin rays. Shovelnose sturgeon in the Lower Platte River reportedly reached maturity at age-6 (Chapter 2) and the oldest shovelnose sturgeon captured during a five-year study was age-19 (J. Hammen 2013, unpublished data). Yet, marginal increment analysis indicates that age estimates from fin rays are likely inaccurate. Estimated ages could be lower than the actual ages if the perceived trend multiple band pairs deposited annually was true. Age underestimation has serious conservation and management implications. For example, if shovelnose sturgeon reach maturity age-6, spawn every four years after reaching maturity (Chapter 2), and lived to age-19, they would have three or four spawning events per lifetime:

$$\frac{(\text{maximum age}) - (\text{age at maturity})}{\text{spawning frequency}} = \text{lifetime spawning events}.$$

However, shovelnose sturgeon would only have one or two lifetime spawning events if age estimates were two times lower than the actual ages, so shovelnose sturgeon would reach maturity at age-3, spawn every four years (Chapter 2), and live 9.5 years.

Pectoral fin rays will likely remain the most popular and practical method for aging sturgeon as they are easily removed and cause minimal injuries to the fish (Brennan and Cailliet 1989). However, we urge that many more location-specific validation experiments be conducted and that an understanding of potential bias in the results be considered. Aging techniques and locations that are yet to be validated should be used with extreme caution. For example, Paragamian and Beamesderfer (2003) used data from recaptured Kootenai River white sturgeon to examine age estimates produced from fin rays. They found that actual ages may be 1.5-2.0 times greater than the estimated ages. Accurate age estimates are crucial for estimating growth, mortality, age frequencies, and year-class assignment, and inaccuracies can result in misguided management decisions. Hamel et al. (2013, unpublished data) assessed the effect of inaccurately assigning shovelnose sturgeon age by  $\pm 3$  years. Growth curves were variable, and mortality rates between overestimated and underestimated ages were up to a two-fold difference (Hamel et al. 2013, unpublished data). We recommend that alternative methods for aging shovelnose be investigated because there is a building body of evidence that pectoral fin rays cannot be used reliably with the current technology. Additionally, a more rigorous evaluation of age estimates from fin rays (e.g., mark recapture, rearing known-age fish) is warranted. The non-lethal removal of fin rays is an attractive age estimation method for species exhibiting population declines such as the shovelnose sturgeon. However, it is important to understand that age estimates of shovelnose sturgeon from fin ray cross sections are erroneous, and the associated costs of errors in age estimates should be acknowledged and remain within a level of acceptability dependent on specific management objectives.

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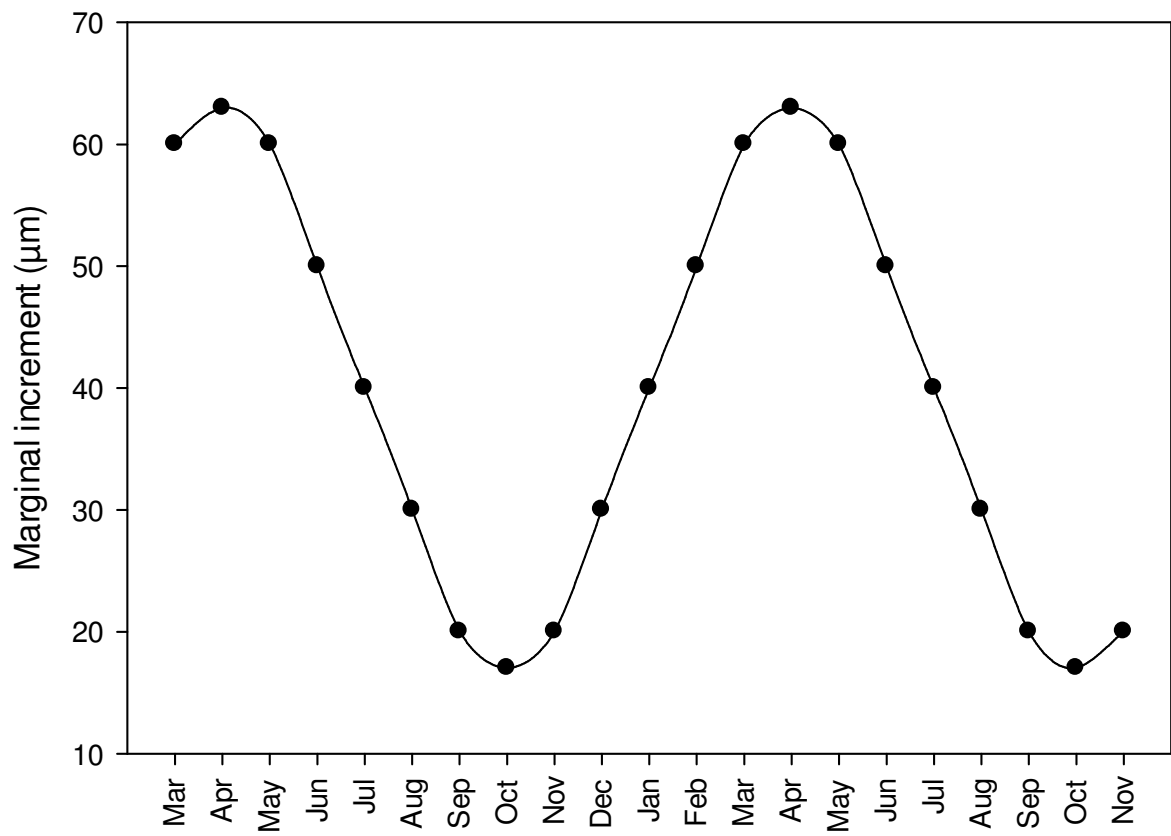


Figure 3.1. Theoretical monthly marginal increment measurements on fin rays from shovelnose sturgeon if translucent and opaque bands on fin rays reflect somatic growth, and if growth follows a predictable yearly cycle.

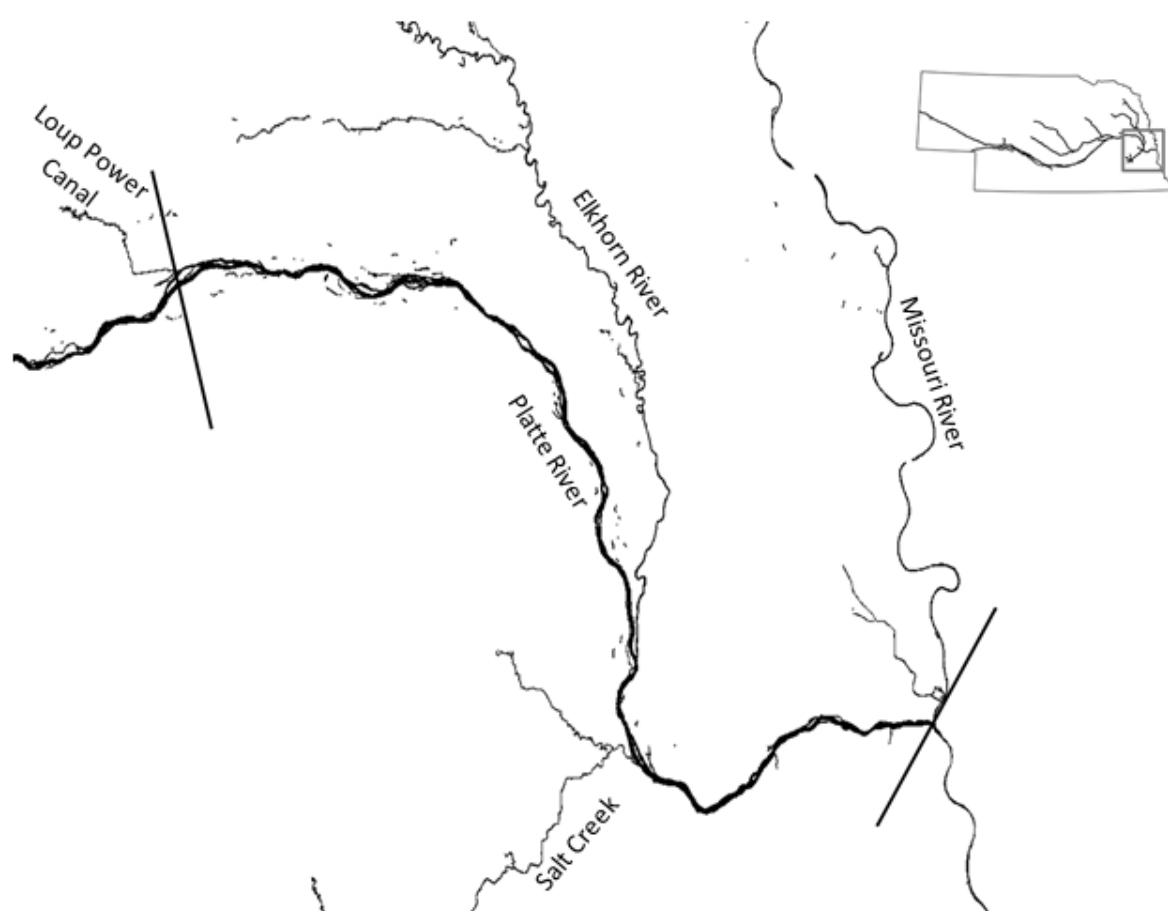


Figure 3.2. Map of Lower Platte River extending between the confluence with the Missouri River upstream to the confluence with the Loup River. Sampling was conducted in the Platte River between the nearly vertical solid lines.

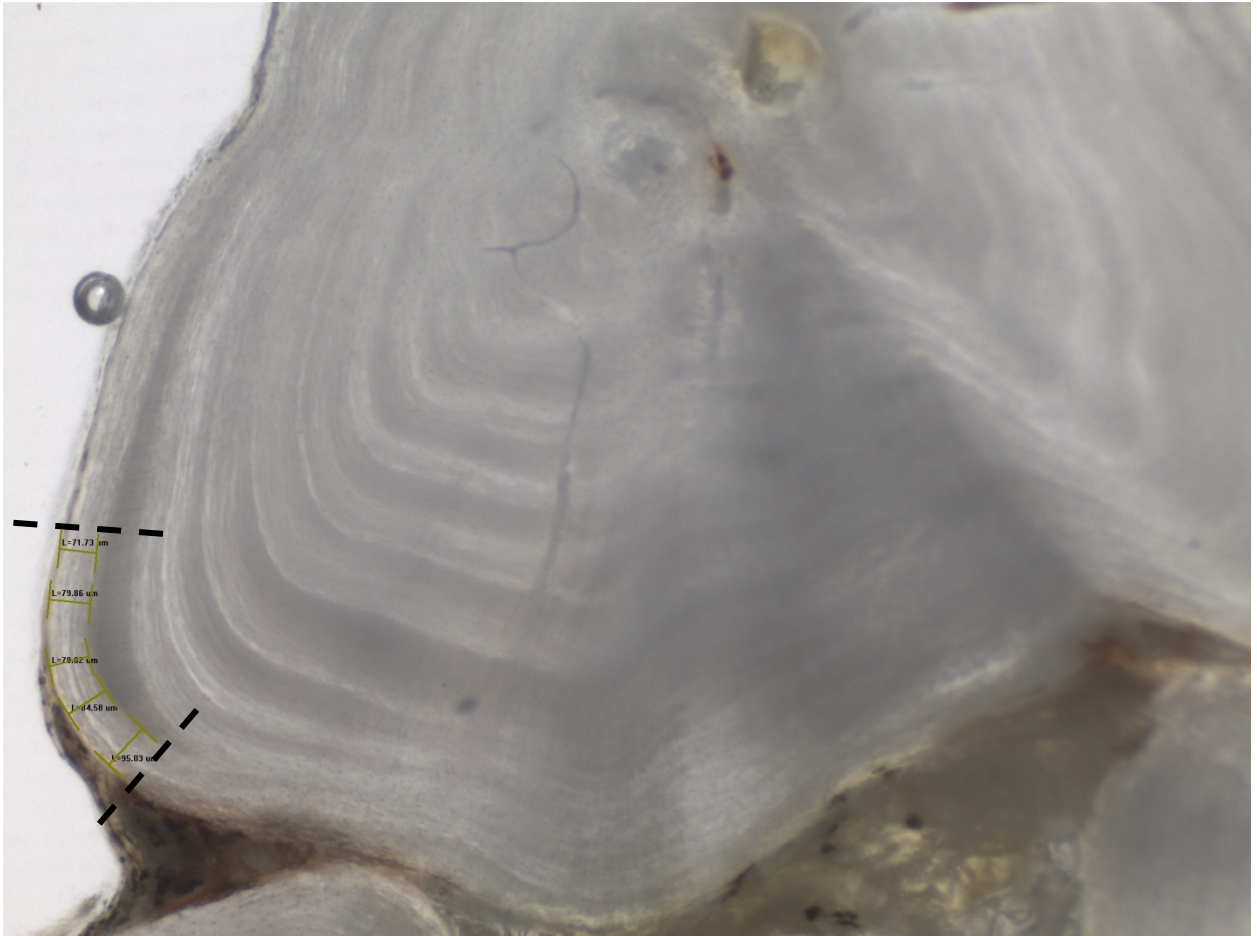


Figure 3.3. Location on ventral, posterior lobe of the fin ray where 5 marginal increment length measurements were taken (area between dashed lines).

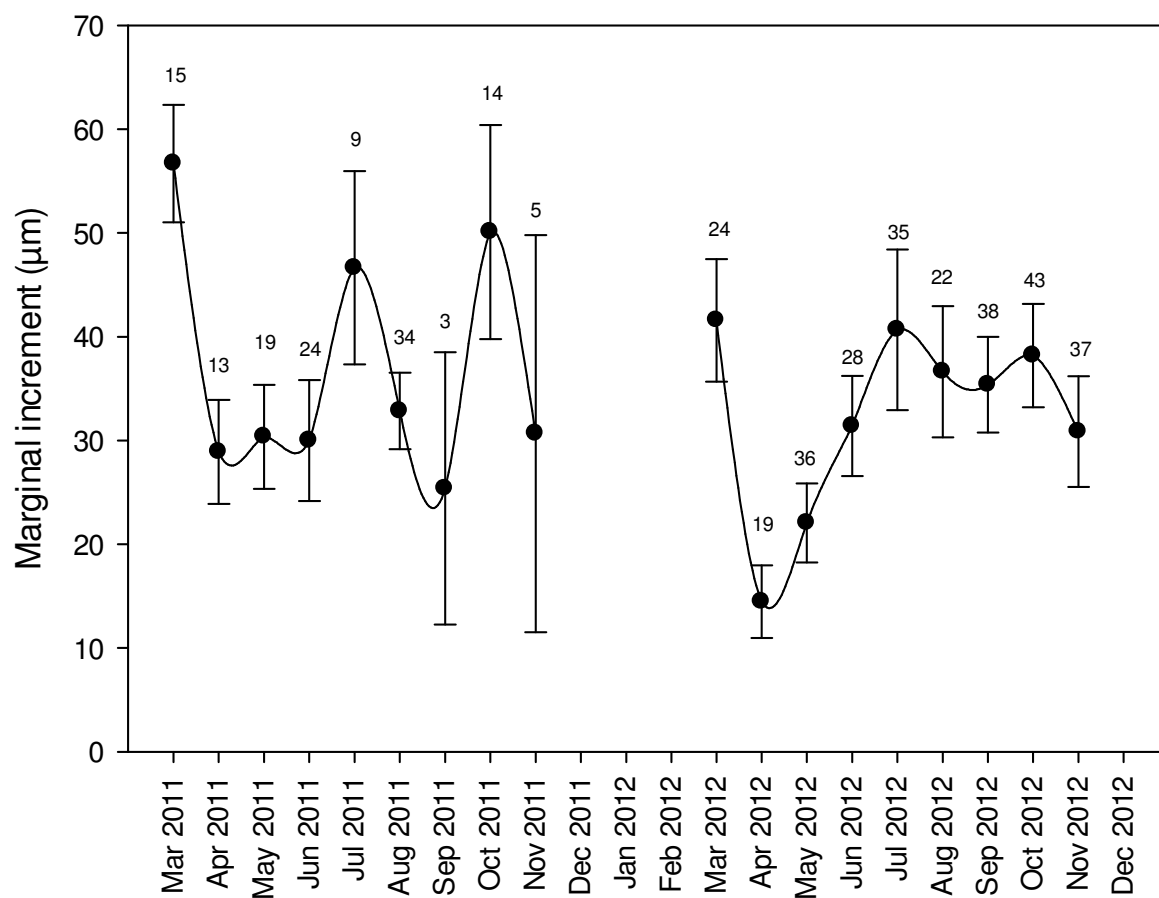


Figure 3.4. Mean  $\pm$  SE marginal increment measurements from fin rays taken from shovelnose sturgeon captured in the Lower Platte River between March and November in 2011 and 2012. Numbers above the error bars indicate sample size for the given month.

## CHAPTER 4: CONCLUSIONS AND MANAGEMENT CONSIDERATIONS

An understanding of reproductive characteristics is vital for proper management of fish populations. This study has described the reproductive cycle and fecundity of shovelnose sturgeon in the Lower Platte River for the first time. Female shovelnose sturgeon reached maturity at a minimum fork length of 449 mm and age- 6. Females appear to spawn every four to six years once they have reached maturity. Total fecundity of black-egg females was  $16,098 \pm 1103$  eggs (mean+ SE), and egg size was  $2.401 \pm 0.051$  mm (mean + SE). Fecundity of mature, female shovelnose sturgeon was positively correlated with fish size (length and weight) and age, with weight being the best predictor of fecundity. Male shovelnose sturgeon reached maturity at a minimum fork length of 453 mm and age-6. Males appear to spawn every three years once they have reached maturity. The proportion of shovelnose sturgeon in spawning condition peaked during spring (May-April) and fall (September-October), indicating that shovelnose sturgeon spawning activities in the Lower Platte River may be bimodal. Additionally, annuli formation in pectoral fin rays was examined using marginal increment analysis. Visually, there were two complete cycles of increasing and decreasing increment values between March and November within each year. Marginal increment peaked in the months of March, July, and October and peaks were followed by a decrease in increment length during the months of April, September, and November. However, there were no statistical differences in mean marginal increments between months in either year. The current method and interpretation of using pectoral fin rays for age estimates is likely leading to errors in age estimates.

## MANAGEMENT RECOMMENDATIONS

Shovelnose sturgeon in the Lower Platte River are maturing earlier, spawning less frequently (Chapter 2), and living shorter lives (J. Hammen 2013, unpublished data) than shovelnose sturgeon in other areas. These life history traits, specific to shovelnose sturgeon in the Lower Platte River, have implications for their reproductive potential. Total fecundity of mature, female shovelnose sturgeon in the Lower Platte River was positively correlated with fish length and weight. Thus, early maturing individuals (i.e., shorter length and lighter weight) are producing fewer eggs. The reproductive potential and population sustainability will decline if the selective pressures in the Lower Platte River continue to drive size-at-maturity down.

***1. Identify selective pressures and the magnitude of their effect on shovelnose sturgeon in the Lower Platte River.*** Shovelnose sturgeon in the Lower Platte River may be experiencing selective pressures from extreme environmental conditions as well as harvest, causing a shift in reproductive strategy. Dramatic diel fluctuations in discharge and gage height from hydropeaking and irrigation withdrawals are common. Altered flow regimes have been shown to reduce abundances of aquatic insects (Elser et al. 1977; Gislason 1985), as well as affecting the ability of shovelnose sturgeon to find aquatic insects upon which to forage (Modde and Schmulbach 1977). Fluctuating water levels in the Lower Platte River are continuously changing the type and amount of habitat available. Additional work on shovelnose sturgeon-habitat correlations and how shovelnose sturgeon respond to accessibility of habitats may show the effects of continuously changing habitat availability due to highly-fluctuating discharge and gage height. In addition to fluctuating discharge, shovelnose sturgeon in the Lower Platte River are subjected to high summer water temperatures. In 2012, Nebraska experienced extreme

drought, and we observed many shovelnose sturgeon mortalities throughout the entire Lower Platte River. Daily maximum water temperatures in July, 2012 exceeded 30°C and exceeded 35°C on several days (USGS gaging station 06805500). The demand for limited water supplies continues to increase throughout the Platte River basin (NRC 2005; USDOI 2006). Therefore, there is a need to gain a better understanding of the selective pressures being forced on all life-stages of shovelnose sturgeon in the Lower Platte River.

***2. Identify angler harvest pressures on shovelnose sturgeon in the Lower Platte River.***

Harvest of shovelnose sturgeon increases mortality and has the potential to shift life-history traits to earlier maturation. A better understanding of shovelnose sturgeon harvest on the Lower Platte River is needed to determine if harvest is a factor leading to early maturation of shovelnose sturgeon in the Lower Platte River. Recreational angling and harvest of shovelnose sturgeon has been documented (Holland and Peters 1994; Latka 1994; Peters and Parham 2008), and harvest of recreationally caught sturgeon has been shown to exceed 73 percent (Holland and Peters 1994). The University of Nebraska – Lincoln did a recent creel survey, but information collected on shovelnose sturgeon harvest was limited. The University of Nebraska – Lincoln creel survey was limited to only surveying anglers fishing from the bank at three public access points during April and May (personal communication, M. Hamel, University of Nebraska). We observed many anglers at private access points as well as airboat anglers, and angler-recaptured shovelnose sturgeon were reported from areas other than public access points (personal communication, M. Hamel, University of Nebraska). A roving creel survey from an airboat should be conducted to include increased efforts at high-use times (e.g., weekends and nights). If harvest has a substantial effect on the shovelnose sturgeon mortality in the Lower Platte River, season closures, decreased bag limits, and/or length limits could be implemented to protect the population from over harvest.



**3. Determine the influence of hermaphroditism on population dynamics.** There was a high rate of occurrence of hermaphroditism in the six kilometer stretch of the Lower Platte River directly above the confluence of the Platte and Missouri rivers when compared to reported rates from the Mississippi River (Tripp 2004; Colombo et al. 2007) and Missouri River (Moos 1978). Research to determine if the high rate of hermaphroditism in the six kilometer stretch above the confluence of the Platte and Missouri rivers has adverse effects on the shovelnose sturgeon population is needed. All cases of hermaphroditism in this study involved males having small patches of oogonia. Effects of hermaphroditism may not be as deleterious to the population as could be if females had small patches of developing sperm. Female shovelnose sturgeon in the Lower Platte River likely require a larger energy investment than males do to produce mature gametes. In addition, the spawning cycle for females is longer than it is for males. Increased energetic needs to produce mature gametes and a longer spawning cycle in female shovelnose sturgeon may indicate that female gamete production is the limiting factor between male and female gamete production. Schwarz et al. (2006) identified high water temperatures and exposure to environmental contaminants as possible factors leading to adverse reproductive conditions of shovelnose sturgeon throughout the Lower Platte River. Schwarz et al. (2006) offered several solutions to minimize exposure to environmental contaminants and adverse water quality conditions including: strengthening water quality standards, limiting pollutant discharges in National Pollutant Discharge and Elimination Systems permits, increasing river flows to avoid high water temperatures during the spawning and rearing period, and implementing Best Management Practices to include: stream bank fencing, relocating livestock feedlots away from streams, constructing roofs over concentrated livestock feeding areas, and establishing filter strips adjacent to stream banks (Schwarz et al. 2006).

**4. Explore alternative aging techniques.** Fin ray based age estimates for shovelnose sturgeon in the Lower Platte River are likely inaccurate. Inaccuracies in age estimates can lead to errors in estimating growth, mortality, age frequencies, age at maturity, and year-class assignment, and could result in misguided management decisions. Hamel et al. (2013, unpublished data) assessed the effect of inaccurately assigning shovelnose sturgeon age by  $\pm 3$  years. Growth curves were variable, and mortality rates between overestimated and underestimated ages were up to a two-fold difference (Hamel et al. 2013, unpublished data). Visual trends in mean, monthly marginal increment measurements were consistent between 2011 and 2012, although not statistically different. Continuing marginal increment analysis with an increased sample size within each year would help clarify if the trend of multiple peaks within one year was an accurate assessment. Furthermore, measuring fin ray marginal increment distances from shovelnose sturgeon captured in winter months (i.e., December, January, February) would provide additional insights into ring deposition that is currently lacking from this study. The interpretation of age from pectoral fin rays could be adjusted so that multiple bands equated to one lapsed year if the trend of multiple marginal increment peaks continues and is deemed significant. Additionally, I recommend that alternative methods for aging shovelnose sturgeon in the Lower Platte River be investigated. A more rigorous evaluation of age estimates from fin rays (e.g., mark recapture, rearing known-age fish) is warranted. The non-lethal removal of fin rays will likely remain an attractive age estimation method for species exhibiting population declines such as the shovelnose sturgeon. However, it is important to understand that age estimates of shovelnose sturgeon in the Lower Platte River from fin ray cross sections are biased. Likewise, the associated costs of errors in age estimates should be acknowledged and remain within a level of acceptability dependent on specific management objectives.

**5. Describe shovelnose sturgeon early life-stage habitat use in the Lower Platte River.**

Efforts should be made to determine if shovelnose sturgeon spawn in the Lower Platte River. Peters and Parham (2008) captured some sturgeon larvae between 1998 and 2004 in the Lower Platte River, but the number collected was small (n=14). None of the captured female sturgeon from this study were in the act of expelling eggs (stage FV); therefore, I cannot definitively say that shovelnose sturgeon use the Lower Platte River as a spawning location. If shovelnose sturgeon do regularly spawn in the Lower Platte River, sampling effort should be put towards capturing larval shovelnose sturgeon in the Lower Platte River. The capture of larval shovelnose sturgeon would provide insights into spawn timing and the relative prevalence of spring and fall spawning strategies as well as habitat use and flow requirements.

**6. Examine reproductive characteristics of other long-lived species occupying the Lower Platte River.** Conditions in the Lower Platte River seem to be selecting for an early maturing life-history strategy for shovelnose sturgeon. It is possible that other long-lived species (e.g., pallid sturgeon) that occupy the Lower Platte River may be experiencing some of the same selective pressures from dramatic diel fluctuations in discharge, habitat availability, and extreme summer temperatures. The Comprehensive Sturgeon Research Program (CSRP), a U.S. Geological Survey (USGS) program designed to study the reproduction and survival of pallid sturgeon and shovelnose sturgeon in the Missouri River, has made extensive use of shovelnose sturgeon as a model for understanding pallid sturgeon reproductive ecology and physiology. A study similar to Chapter 2 should be conducted to define reproductive characteristics of mature pallid sturgeon in the Lower Platte River to determine if the same trends (i.e., early maturation) are evident. Non-invasive, non-lethal methods for examining internal reproductive organs of pallid sturgeon exist. A combination of ultrasound and endoscopy techniques can be used to assess fish sex and track gonad characteristics (Wildhaber et al. 2005; Bryan et al. 2007).

Defining life history strategies of pallid sturgeon in the Lower Platte River would provide valuable information for management decisions striving for the ultimate goal of a self-sustaining population of pallid sturgeon in the Lower Platte River. For example, the reproductive potential and sustainability of pallid sturgeon in the Lower Platte River could be reduced if pallid sturgeon are maturing earlier, producing smaller and fewer eggs, spawning less frequently, and living shorter lives. Population augmentation from stocking efforts alone likely will not lead to a sustainable pallid sturgeon population if reproductive success is low. Rather, efforts would need to be directed towards water allocation and habitat improvements to improve reproductive success.

***6. Examine reproductive characteristics of shovelnose sturgeon in the Missouri River.***

Awareness of reproductive strategies of shovelnose sturgeon in the Lower Platte River and comparisons to shovelnose sturgeon in other areas throughout their range highlight the need to assess reproduction on a system-specific scale. Movements of shovelnose sturgeon between the Lower Platte River and the channelized Missouri River are common (J. Hammen 2013, unpublished data), and genetic analysis suggests no differences between shovelnose sturgeon captured in the Lower Platte River and the channelized Missouri River (Heist 2012). Defining reproductive characteristics of shovelnose sturgeon in the channelized Missouri River would be beneficial for management of the shovelnose sturgeon population. Size at maturity of shovelnose sturgeon in the unchannelized Missouri River (Moos 1978) was similar to shovelnose sturgeon in the Lower Platte River. It is likely that reproductive traits of shovelnose sturgeon in the channelized Missouri River would be very similar to those of the Platte River because of proximity, connectivity, and genetic similarities between individuals caught in the Lower Platte River and the channelized Missouri River. Similar life history traits between the Lower Platte River and channelized Missouri River would provide additional evidence that shovelnose

sturgeon in both systems are a part of the same population and are responding to similar environmental and human stressors. Management efforts would need to be focused on a scale that viewed the Lower Platte River and the channelized Missouri River as one system being used by the population.

***7. Describe habitat use for all life-stages of shovelnose sturgeon in the Lower Platte River and Missouri River.*** Little information is known about shovelnose sturgeon habitat use throughout all life-stages, especially for early life-stages. Shovelnose sturgeon move between the Lower Platte River and the Missouri River (J. Hammen 2013, unpublished data), yet the extent to which habitats in either system are used is relatively unknown. For example, larval shovelnose sturgeon in the Lower Platte River may experience extreme flow and temperature conditions (Chapter 2), but drift may bring larvae out of the Lower Platte River and into the Missouri River. Larvae may not be experiencing selective pressures of the Lower Platte River if they are ultimately ending in the Missouri River. Rather, they would endure a different set of conditions that the Missouri River offers (e.g., high water velocities, lack of shallow water habitat). An understanding of habitat use by all life-stages of shovelnose sturgeon would provide insight into how fluctuating flows, habitat availability, and habitat quality might be affecting the population.

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APPENDIX A: HISTOLOGICAL AND WHOLE GONAD IMAGES OF MALE AND FEMALE SHOVELNSOE  
STURGEON GONAD DEVELOPMENT STAGES

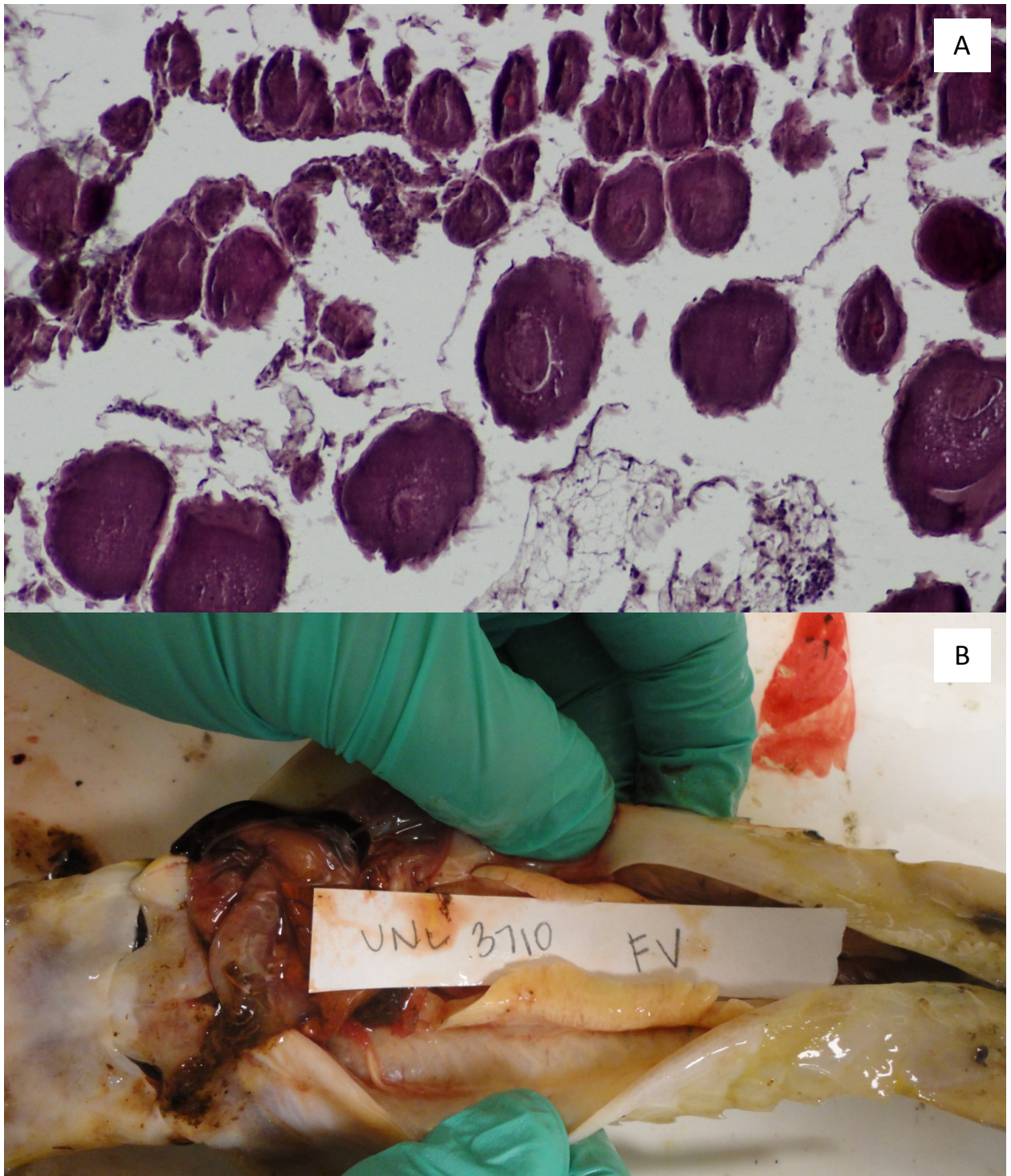


Figure A.5. Comparative assessment between histological (A) and whole gonad (B) images of virgin female (Fv).



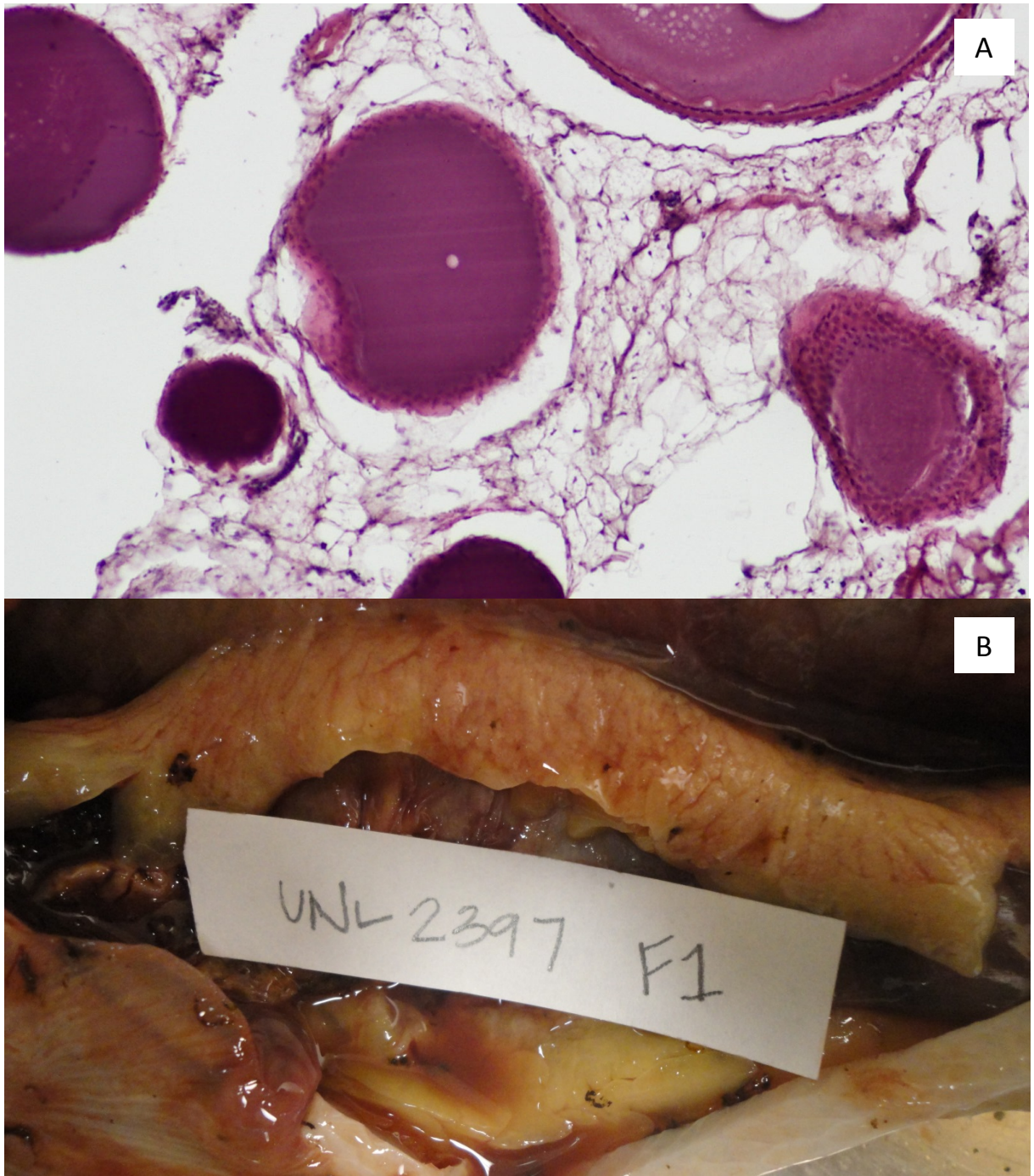


Figure A. 6. Comparative assessment between histological (A) and whole gonad (B) images of stage 1 female (F1).



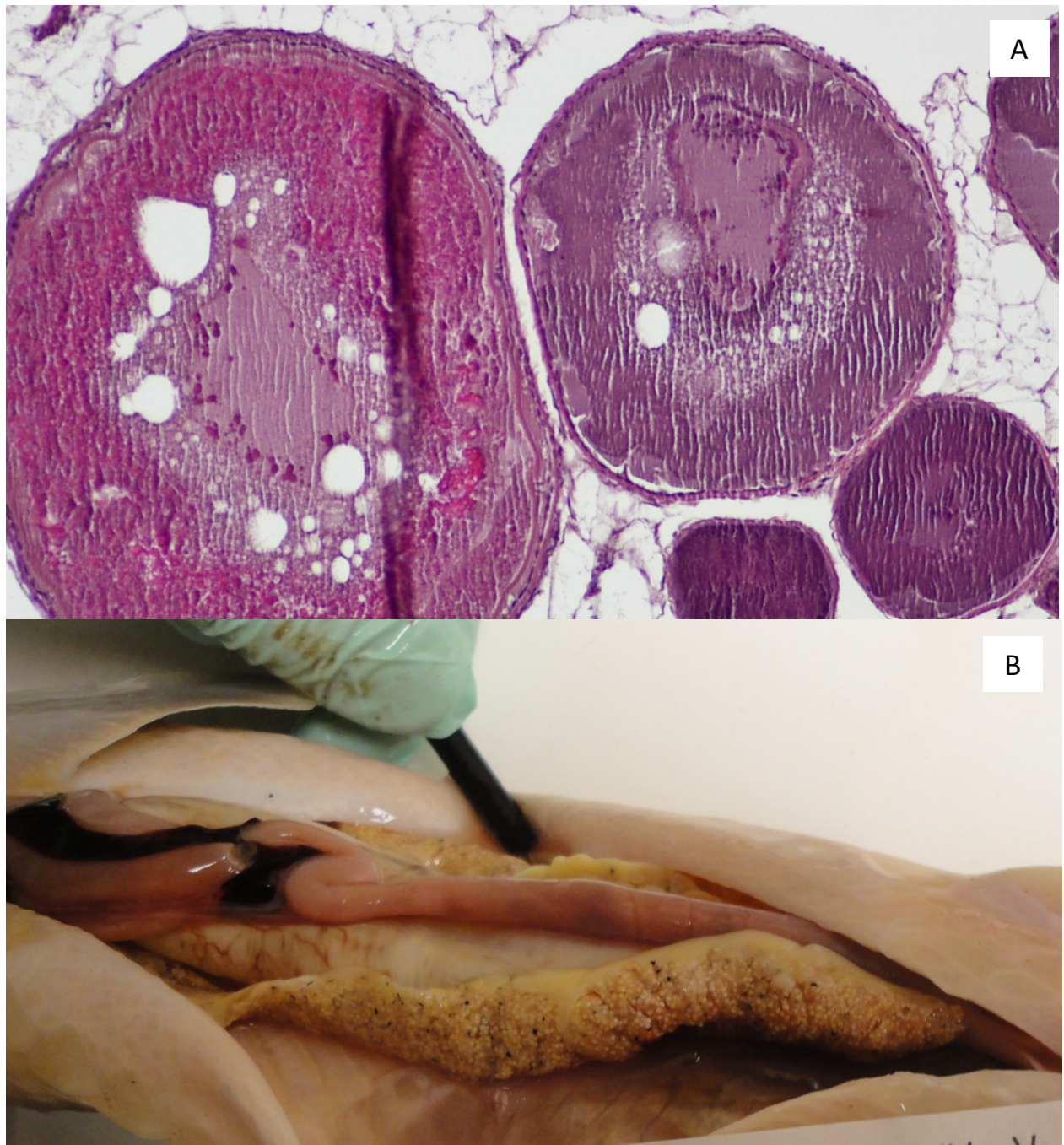


Figure A.7. Comparative assessment between histological (A) and whole gonad (B) images of stage 2 female (FII). This individual has atretic oocytes (black specks in whole gonad image) that would be evidence of previously having mature eggs.



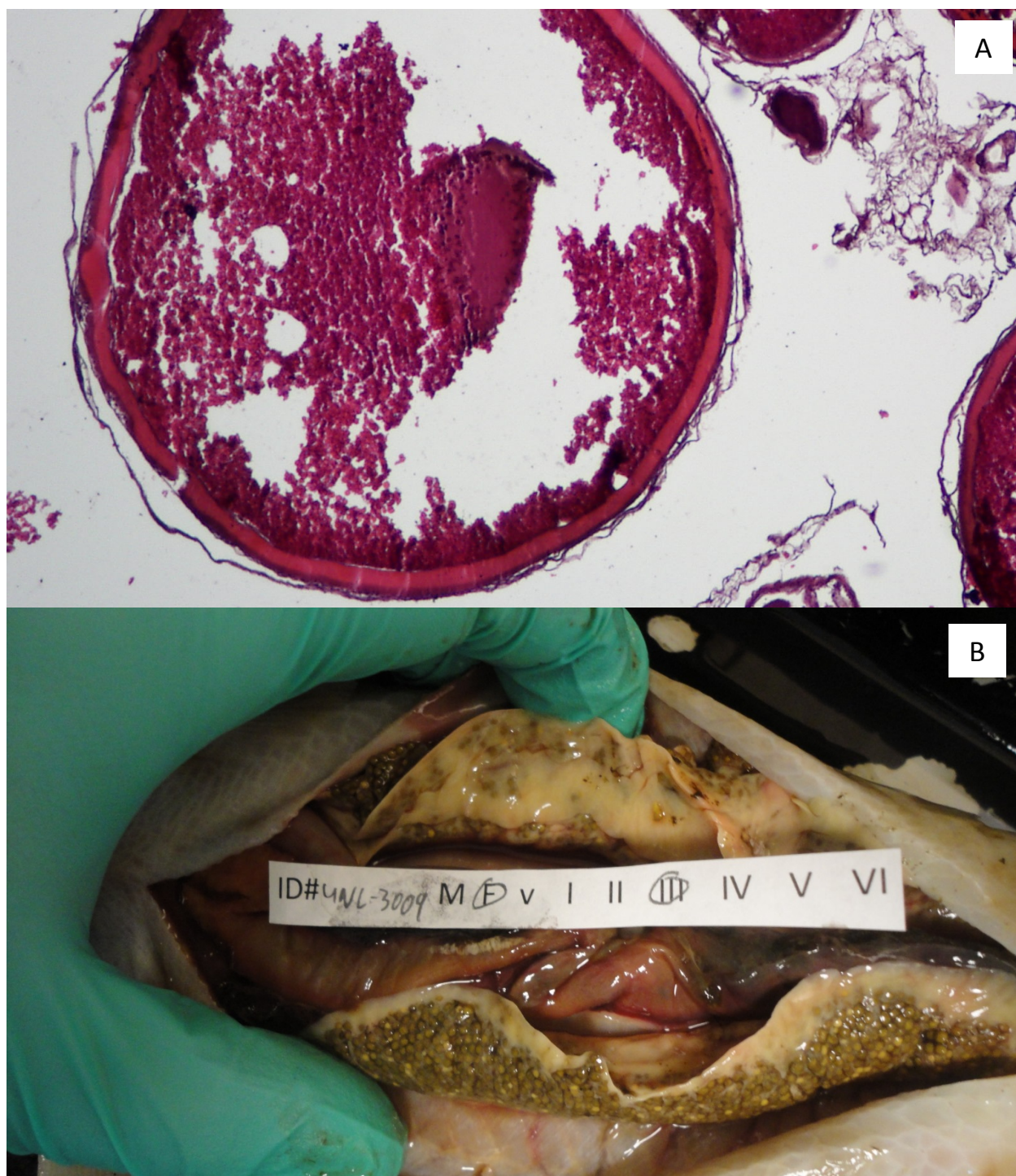


Figure A.8. Comparative assessment between histological (A) and whole gonad (B) images of stage 3 female (FIII).



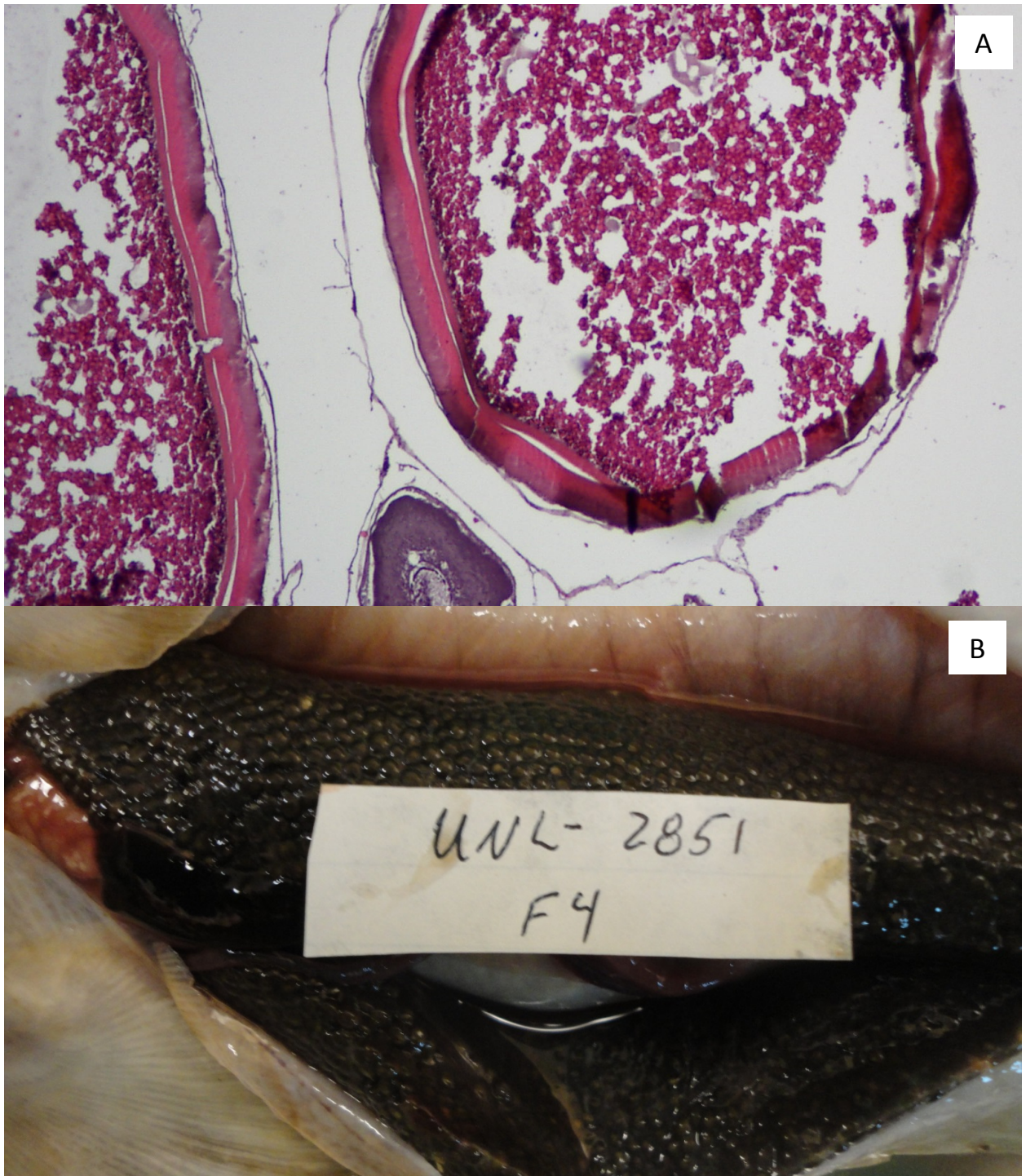


Figure A.9. Comparative assessment between histological (A) and whole gonad (B) images of stage 4 female (FIV).



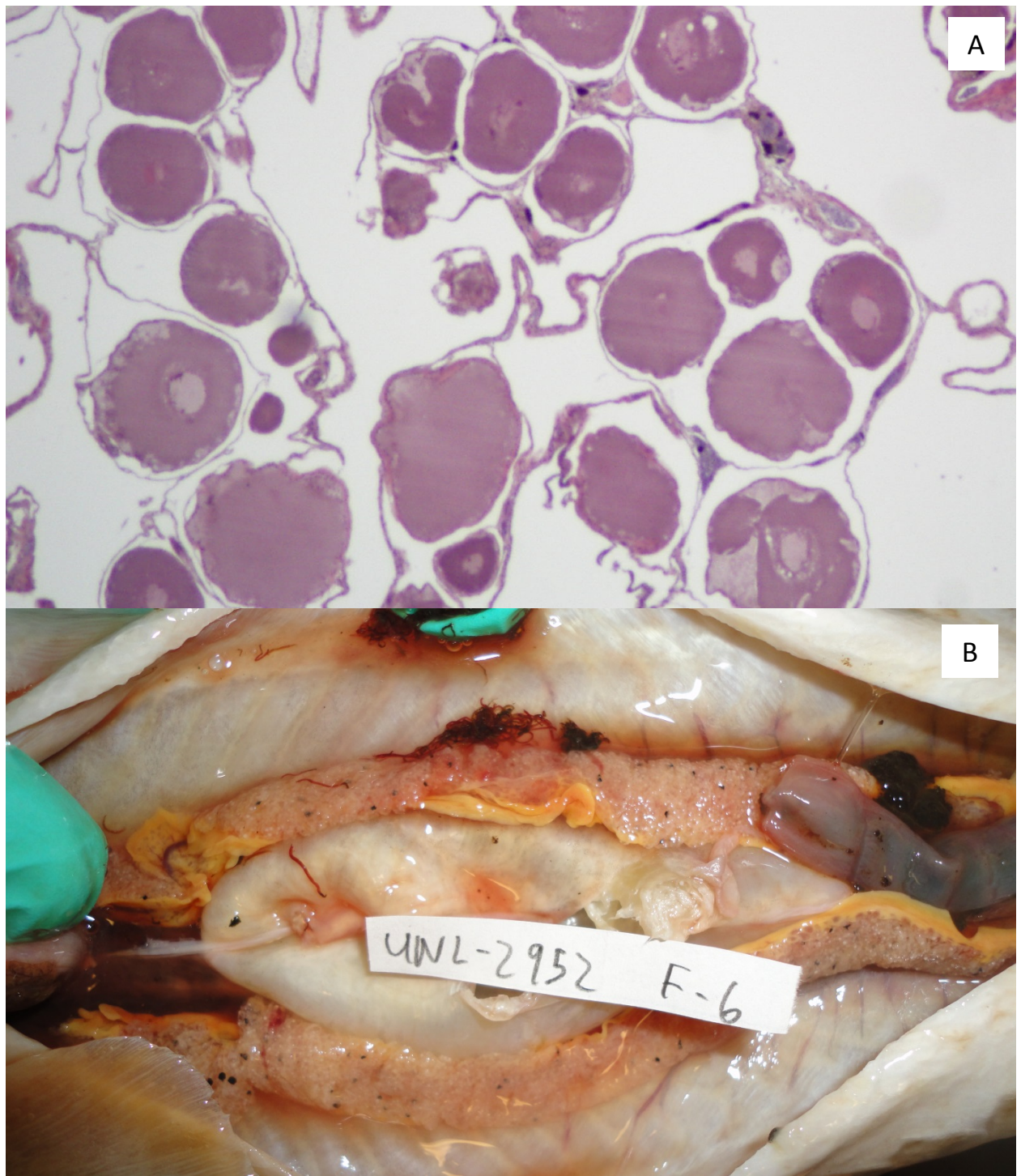


Figure A.10. Comparative assessment between histological (A) and whole gonad (B) images of stage 6 female (FVI).



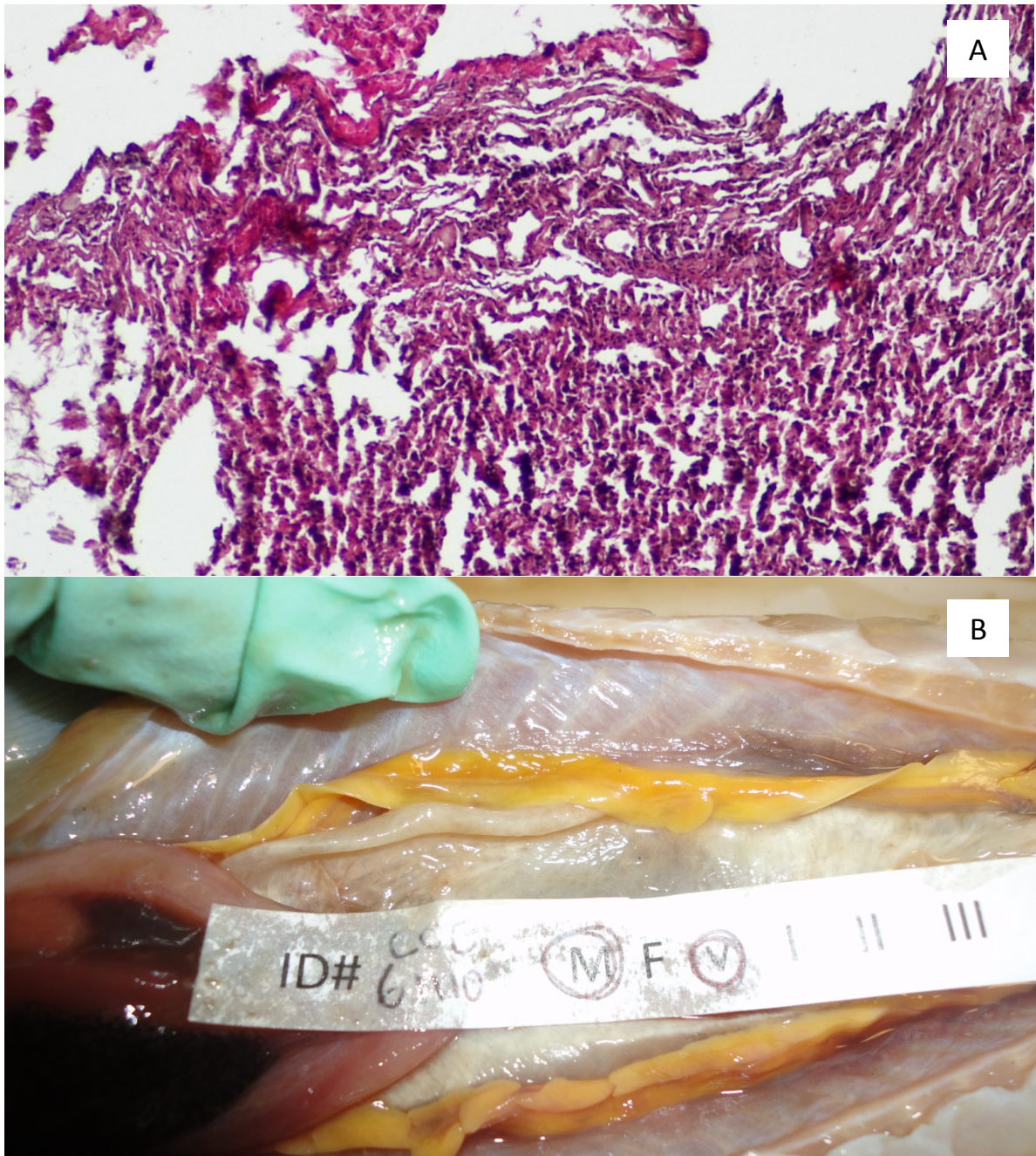


Figure A.1. Comparative assessment between histological (A) and whole gonad (B) images of virgin male (Mv).



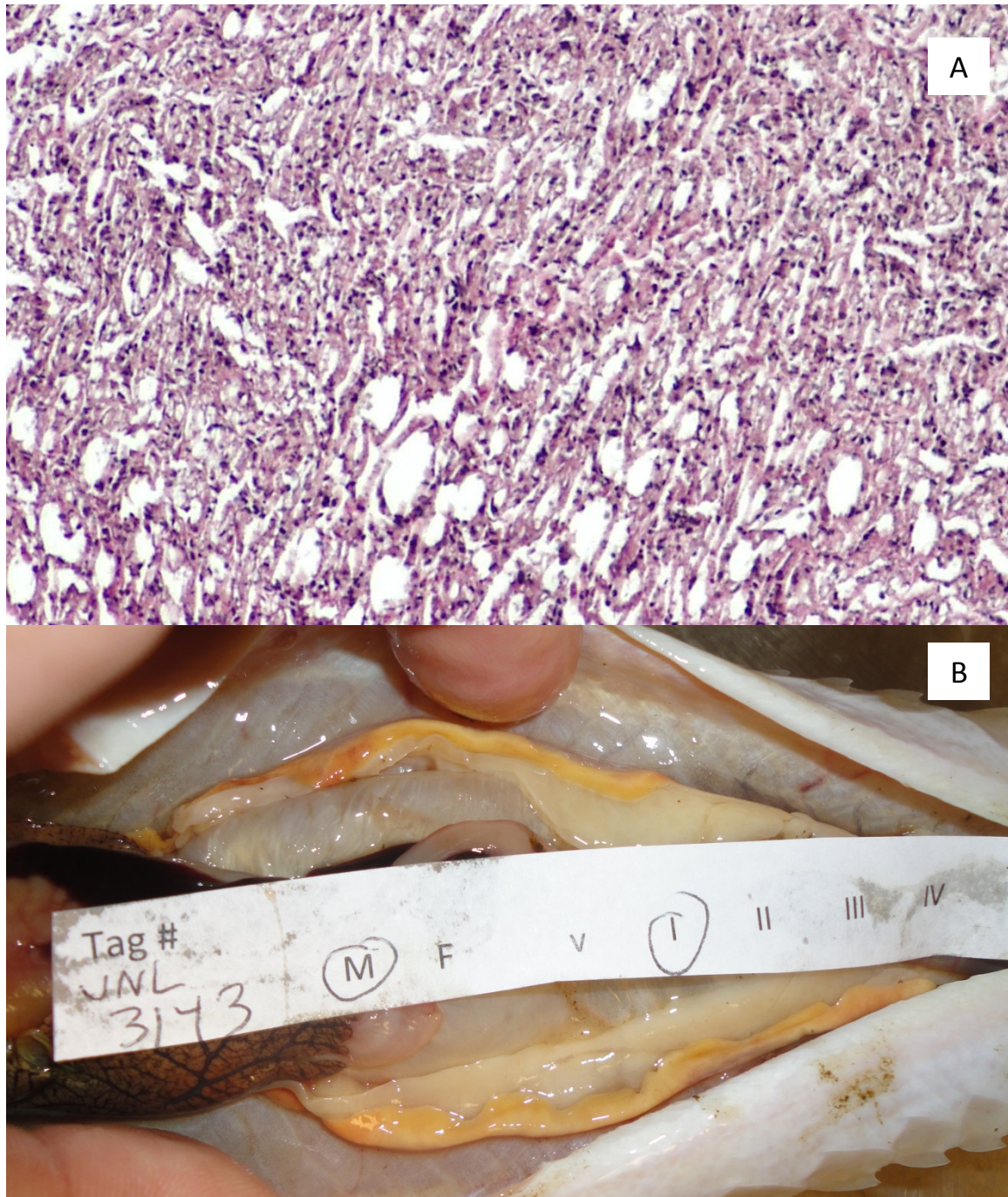


Figure A.2. Comparative assessment between histological (A) and whole gonad (B) images of stage 1 male (MI).



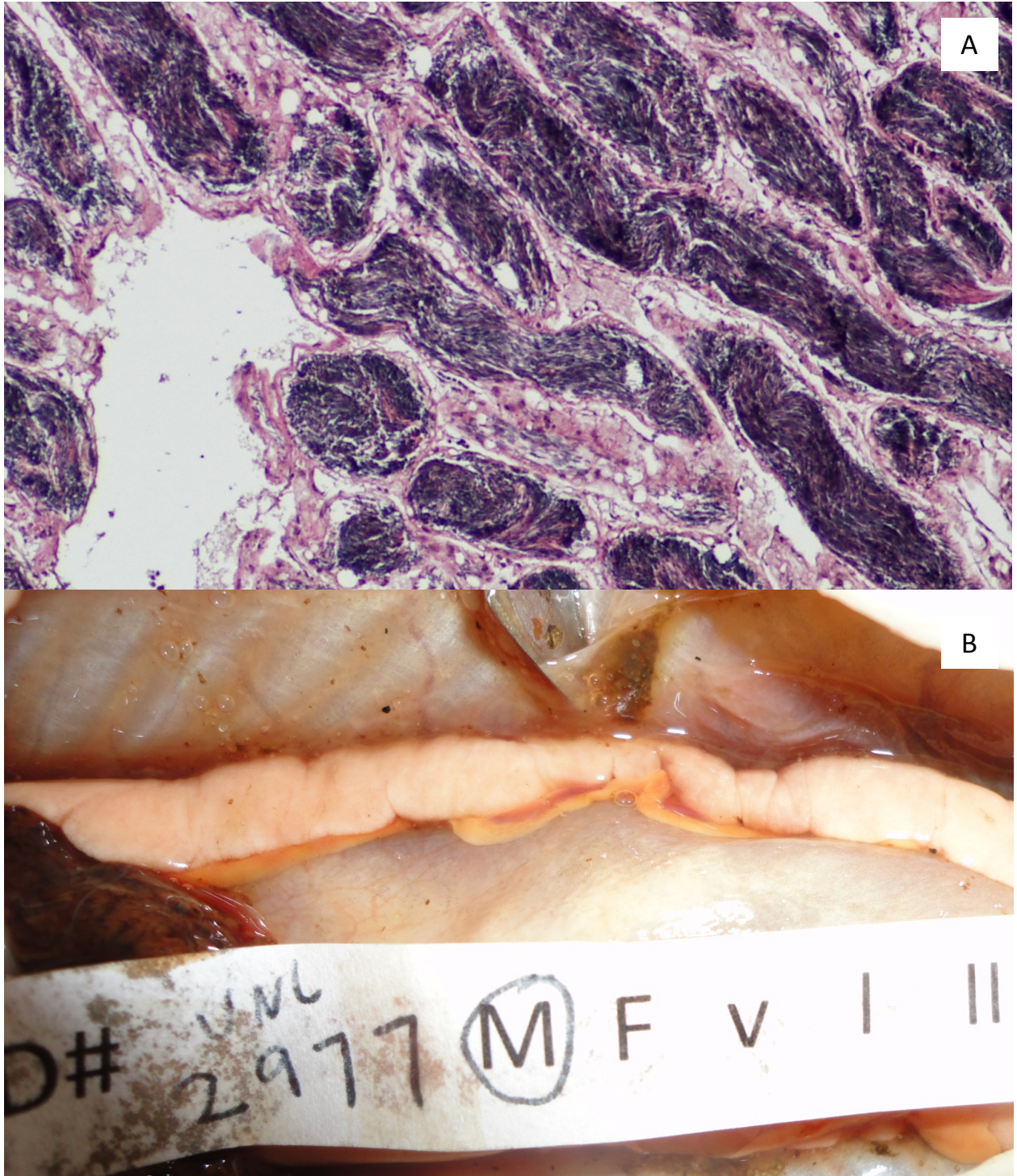


Figure A.3. Comparative assessment between histological (A) and whole gonad (B) images of stage 2 male (MII).



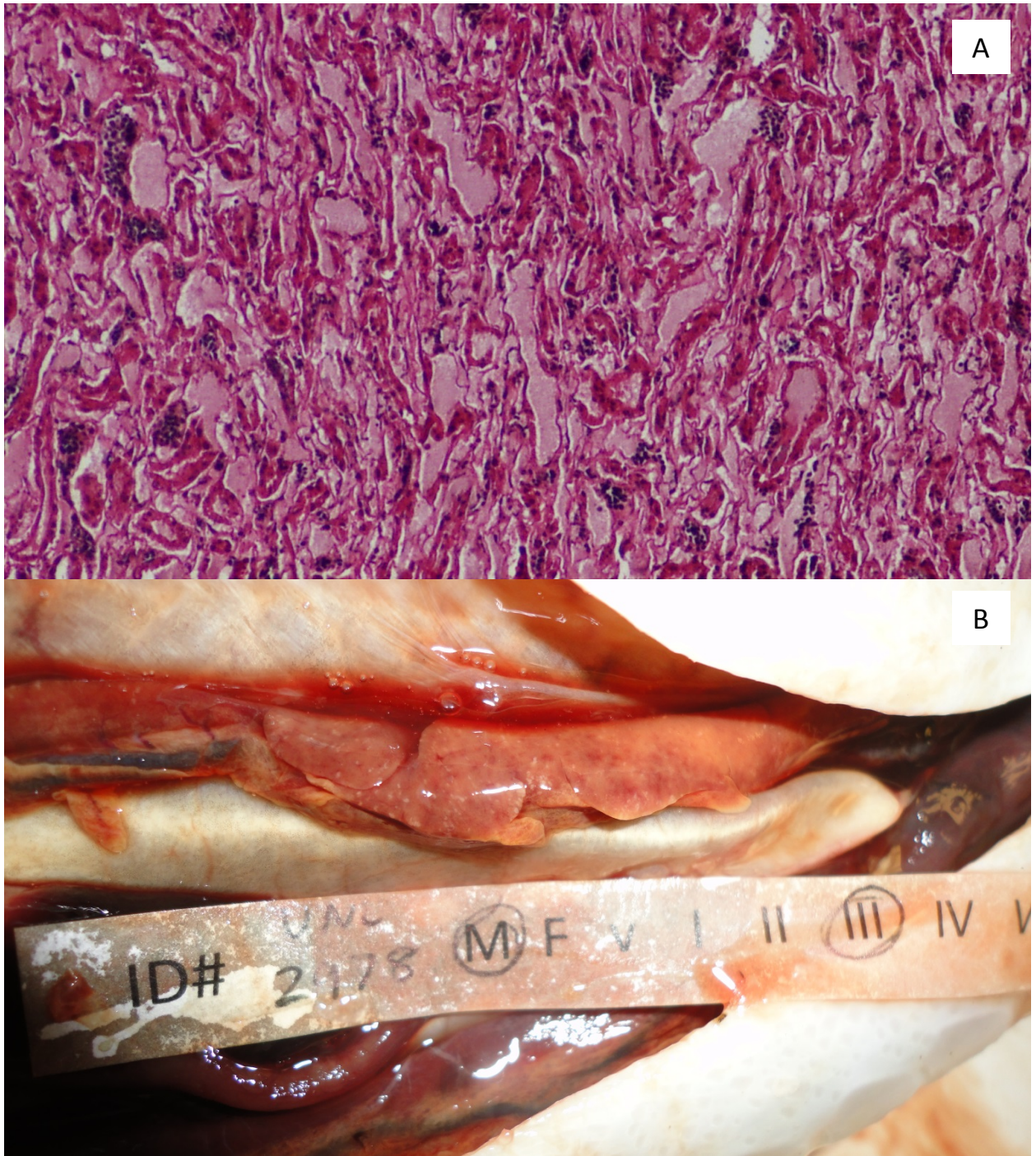


Figure A.4. Comparative assessment between histological (A) and whole gonad (B) images of stage 3 male (MIII).