Four Year Summary Age and Growth Report

For

Shovelnose Sturgeon

Pallid Sturgeon Population Assessment Project and Associated Fish Community Monitoring for the Missouri River

Prepared for the U.S. Army Corps of Engineers – Northwest Division
By:

Kirk Steffensen and Marty Hamel

Nebraska Game and Parks Commission
Fisheries Division
2200 North 33rd Street
Lincoln, NE 68503

February 2008

Executive Summary

Little is known about the population dynamics of most native Missouri River fishes. Accurate age and growth information is needed in order to better understand life history characteristics and to implement management recovery plans. Accurate age information may also be used to derive growth models and to evaluate recruitment success based on various abiotic and biotic factors. The Population Assessment Program recognized the importance of these dynamic rate functions and initiated a basin wide age and growth project for its eight target species. These target species are: shovelnose sturgeon *Scaphirhynchus platorynchus*, speckled chub *Macrhybopsis. aestivalis*, sturgeon chub *M. gelida*, sicklefin chub *M. meeki*, sand shiner *Notropis stramineus, Hybognathus* species (western silvery minnow *H. argyritis*, brassy minnow *H. hankinsoni* and plains minnow *H. placitus*), blue sucker *Cycleptus elongatus* and sauger *Stizostedion canadense*. These native river species are used in addition to pallid sturgeon *S. albus* to aid in the detection of fish community response to changing riverine conditions.

This study examined age and growth characteristics of shovelnose sturgeon throughout the Missouri River basin. Shovelnose sturgeon are the only one of the three North American river sturgeons not listed or listed as a candidate species under the Federal Endangered Species Act. Unlike its close relatives the pallid and Alabama sturgeon *S. suttkusi* , shovelnose sturgeon seem to be more resilient to changes in river flow and habitat manipulations. Although Missouri River shovelnose sturgeon populations appear healthy, there is little known about their population dynamics.

The project area for this study included the Missouri River from Fort Peck Dam (R.M. 1771.5) to the confluence of the Missouri and Mississippi Rivers (R.M. 0.0) and the lower reach of the Kansas River from the Johnson County Weir (R.M. 15.4) to the confluence with the

Missouri River (R.M. 0.0). Shovelnose sturgeon fin rays were collected periodically from December 2003 to April 2007 as a part of the Pallid Sturgeon Population Assessment Program's standardized sampling regime. The primary collection methods were with 30.5-m gill nets, 4.9-m otter trawls and 1.0" trammel nets.

A total of 2,602 fin rays were collected for age and growth analysis. Mean back-calculated fork length-at-last annulus indicated that shovelnose sturgeon grow rapidly during the first year across the entire Missouri River basin. The mean growth for an age-1 fish for all river segments was 190-mm. During their second and third years, growth rates declined to 92-mm and 68-mm, respectively. Comparisons of mean length-at-capture of shovelnose sturgeon collected in 2003 and 2004 revealed no differences between age-2 or age-3; however, differences in mean length-at-capture were observed in three age classes in 2005 and two age classes in 2006. Very few differences were observed between segments for mean Wr from 2003 to 2005. However, in 2006 there were differences in mean Wr were observed for age-2 and age-3 shovelnose sturgeon.

Variable condition and growth patterns were observed across the entire Missouri River for all years and are probably related to local variations in weather, habitat conditions and resource availability. Recruitment of shovelnose sturgeon appears to be fairly consistent in the channelized portion of the Missouri River; however, this is less apparent in the unchannelized reaches. There were fewer shovelnose sturgeon collected in the unchannelized segments of the Missouri River, which may be a function of lower shovelnose sturgeon densities, sampling difficulties or the sampling regime.

Continued age and growth analysis will allow managers to monitor the health of shovelnose sturgeon and relate this to habitat improvements, flow modifications or natural environmental events. In order to further understand population dynamics of shovelnose sturgeon in the Missouri River, we recommend removing the maximum size restraint of 530-mm and maintain collecting 10 fin rays per 10-mm length classes per segment. A full range of shovelnose sturgeon sizes will allow researches to create predictive growth models and to estimate age-specific mortality rates. Although research has shown that there is an increase in variability of age estimates from fin ray sections of older fish, we feel that the additional information gained is justified. Standardization of fin ray collection times and preparation techniques will also help to reduce variability in age estimates.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICIES

Introduction

Pallid sturgeon *Scaphirhynchus albus* are native to large river environments in the Missouri and Mississippi River systems. Due to population declines, pallid sturgeon became a federally listed endangered species in 1990. Modifications of pallid sturgeon habitat by human influences have blocked fish movement, destroyed or altered spawning areas, reduced food sources or ability to obtain food, altered water temperature, reduced turbidity, and altered the natural hydrograph (USFWS 1993). In response to declines in population and lack of recruitment, the United States Fish and Wildlife Service (USFWS) developed a Biological Opinion that made recommendations to the United States Army Corps of Engineers (USACE) to mimic the natural flow regime of the Missouri River and to provide funding for a basin wide pallid sturgeon population assessment. This led the USACE to form the Pallid Sturgeon Population Assessment Team comprised of numerous state and federal agencies. This team developed standard operating procedures (SOP) for long-term pallid sturgeon and associated fish community monitoring in the Missouri River. During the development of the SOP's, the team divided the Missouri river into 14 segments based on changes in physical attributes such as degrading or aggrading stream bed, flow fluctuation, natural hydrograph, stream gradient, geology, water temperature, turbidity, substrate, discrete habitat changes (tributary or tributary influence) and modifications (presence of restoration projects) (Drobish, editor 2007; Figure 1).

Several native river species were selected as target species for the population assessment program to aid in the detection of fish community response to altered riverine conditions. The eight target species were: shovelnose sturgeon *S. platorynchus*, speckled chub *Macrhybopsis aestivalis*, sturgeon chub *M. gelida*, sicklefin chub *M. meeki*, sand shiner

Notropis stramineus, Hybognathus species (western silvery minnow *H. argyritis,* brassy minnow *H. hankinsoni* and plains minnow *H. placitus*), blue sucker *Cycleptus elongates* and sauger *Stizostedion canadense*. More specifically, shovelnose sturgeon were selected as a target species due to their close morphology and physiology to pallid sturgeon. *Macrhybopsis* species were selected because they were thought to be a primary food source for adult pallid sturgeon and have experienced recent declines in population size. *Hybognathus* species, sand shiner and sauger were selected because they would show positive responses to improved river conditions and would show a measurable response in population size. Finally, blue suckers were selected as a possible surrogate species for pallid sturgeon due to similar habitat preferences.

Little is known about the population dynamics of many native Missouri River fishes. Accurate age and growth information is needed in order to better understand life history characteristics and to direct management recovery plans. Accurate age information may also be used to derive growth models and to evaluate recruitment success based on various abiotic and biotic factors. The Population Assessment Program recognized the importance of these dynamic rate functions and initiated a basin wide age and growth project for the eight target species. Each of the target species was assigned to a cooperating agency to minimize work loads and to reduce collection and processing errors. Nebraska Game and Parks Commission (NGPC) took responsibility for shovelnose sturgeon; South Dakota Game, Fish and Parks was responsible for blue suckers; Missouri Department of Conservation was responsible for sauger, *Hybognathus* species and sand shiner; and Montana Fish, Wildlife and Parks was responsible for *Machybopsis* species.

This study examined age and growth characteristics of shovelnose sturgeon throughout the Missouri River basin. Shovelnose sturgeon are the only one of the three North American river sturgeons not listed or listed as a candidate under the Federal Endangered Species Act (Morrow et al. 1998) and are the smallest of eight sturgeon species found in North America (Bailey and Cross 1954; Lee et al. 1980; Morrow et al 1998). Unlike its close relatives, the pallid and Alabama sturgeon, shovelnose sturgeon seem to be more resilient to changes in river flow, habitat manipulations and exploitation. Although Missouri River shovelnose sturgeon populations appear healthy, little is known about their population dynamics. Understanding the dynamic rate functions of shovelnose sturgeon will help guide pallid sturgeon recovery. The objectives of this study were to (1) determine mean length at age for each age class, (2) examine growth, both temporally and spatially, (3) determine year class strength, and (4) examine condition, both temporally and spatially.

The use of pectoral fin rays provides the only non-lethal method for aging *Scaphirhynchus* species. Collins and Smith (1996) reported that growth and survival of shortnose and Atlantic sturgeons were not affected by pectoral fin ray removal and that the wounds healed readily. Parsons et al. (2003) tested shovelnose sturgeon (with and without fin ray removal) swimming performance and station-holding ability in a laboratory swim tunnel. Results indicated that removal of the pectoral fin ray had little effect on station-holding ability. These studies indicate that fin rays can be removed from sturgeon without significantly affecting their ability to survive.

Study Area

The project area included the Missouri River from Fort Peck Dam (R.M. 1771.5) to the confluence of the Missouri and Mississippi Rivers (R.M. 0.0) and the lower reach of the

Kansas River from the Johnson County Weir (R.M. 15.4) to the confluence with the Missouri River (R.M. 0.0). The Biological Opinion divided the Missouri River into river and reservoir reaches and categorized these areas as high, moderate or low priority management areas. The areas which were given high priority designation by the Bi-Op for the pallid sturgeon include Segment Area 2 (Fort Peck Dam, Montana to the headwaters of Lake Sakakawea, North Dakota), Area 8 (Fort Randall Dam, South Dakota to the Mouth of the Niobrara River, Nebraska), and Areas 10 through 15 (Gavins Point Dam, Nebraska/South Dakota to the mouth of the Missouri River at St. Louis, MO).

There are also several areas sampled that were not designated as high priority areas in the Bi-Op. These areas were sampled because of known pallid sturgeon use and include the Kansas River from Johnson County Weir to the mouth and Bi-Op Segment Area 9 (Niobrara River, Nebraska to the headwaters of Lewis and Clark Lake Nebraska/South Dakota). The segments with their corresponding river miles are presented in Table 1.

River segments were divided into an upper and lower sampling universe due to the longitudinal difference as well as the duration of the fish's growing season. Segments 1 – 4 were defined as the upper sampling universe and segments 5 – 14 were designated as the lower sampling universe. The upper sampling universe is a continuous 203.5 river mile reach between Fort Peck Dam and the headwaters of Lake Sakakawea. The Yellowstone River has a major impact on the lower 14 miles of this reach. The lower sampling universe is divided by Gavins Point Dam. There are two river segments that are located above the dam (i.e., segments 5 and 6) and consist of 55 river miles that is divided by the Niobrara River. Below Gavins Point Dam, the remaining 811 river miles to the confluence of the Mississippi River are free-flowing. The first 61 miles (ssegment 7) is unchannelized and remains in an unaltered state. The remaining 750 river miles (segments 8 – 14) have been highly engineered into a channelized river that is heavily influenced by several large tributaries (e.g., Platte River, Kansas River, etc.).

Methods

Shovelnose sturgeon fin rays were collected from December 2003 to April 2007 as a part of the Pallid Sturgeon Population Assessment Program's standardized sampling regime (Drobish 2007; Table 2). It has been documented that annuli formation begins in May and is completed by July and August (Whiteman et al. 2004); therefore, fin rays were collected during the late fall/early winter and spring seasons. The primary collection method was with 30.5-m gill net composed of four, 6-m panels of varying mesh sizes. A 4.9-m otter trawl (19.05-mm bar mesh for the body and 6.35-mm mesh for the cod end) and a 1.0" trammel net (1.0-in bar mesh for the inner wall and 8.0-in bar mesh for the outer wall) were used to sample river segments where gill nets were not used as a part of the standardized sampling protocols.

The marginal ray of the left pectoral fin was removed from 10 shovelnose sturgeon per 10-mm length interval for each segment. Fin rays were only collected from fish less than 530-mm fork length due to the reported variability observed in aging adult shovelnose sturgeon with fin rays (Morrow et al. 1998; Whiteman et al. 2004). Fin rays were cut parallel and close to the body, while keeping the remaining fin in tact. The severed fin ray was then separated from the attached fin with a knife, scalpel, or scissors (Drobish 2007). After removal, fin rays where placed into a coin envelope with individual identification numbers. All shovelnose sturgeon fin rays were sent to NGPC for further processing.

Fin ray preparation followed a technique outlined in Koch and Quist (2007) and consisted of embedding fin rays in epoxy resin and cross-sectioning them (0.75 mm thick sections) with a low-speed Buehler Isomet saw. Three to four cross-sections were taken from each fin ray and were mounted onto a glass slide using cytoseal, which is a high-viscosity medium composed of acrylic resin. Cross-sections were examined with a dissecting microscope and transmitted light at 15-40x magnification. Fin rays were digitized using a digital camera and were viewed on a computer to determine the best quality picture for each fin ray.

Analysis

Two readers independently examined fin ray cross-sections and determined fish age in years. Annuli were assumed to be laid down on the structure when a continuous translucent band was followed by a dark, opaque band. One pair of the opaque and translucent bands was equal to one full year of growth. When age estimates differed, fin rays were viewed a third time by both readers to develop a final consensus. Measurements of distances to annuli and to edges of fin rays were examined in an aging software program (Traitement Numérique de Pièces Calcifiées [TNPC]) for use in back-calculation procedures. We used the Dahl-Lee method for back-calculating ages because it incorporates a correction factor for using bony structures that are present at hatching. The Dahl-Lee formula is:

$$L_i = (S_i/Sc)Lc,$$

where L_i = back-calculated fish body length at annulus i, Lc = fish body length at capture, S_i = aging-structure annulus i, Sc = aging-structure radius at capture, and c = intercept from the regression of fish body length vs. mean fin ray radius.

Mean length at capture was calculated for each age class and was compared between river segments for each year with a one-way ANOVA. A Tukeys test was used for all post-hoc comparisons. Age data from each segment and year was checked for normality. The data appeared to follow a normal distribution; therefore, were not under any direct violations of specific ANOVA assumptions. Pooled segments (i.e., Upper and Lower Universe) were compared with an independent *t*-test. All comparisons were tested at the significance level of 0.10. An age-length key (Isley and Grabowski 2007) was also generated for each river segment so that an estimated age could be applied to all remaining shovelnose sturgeon that are captured during standard sampling endeavors.

Relative weight of shovelnose sturgeon was calculated using the formula:

$$Wr = 100 * (W / Ws);$$

where W is weight of the individual and Ws is the length-specific standard weight value for the species. Quist et al. (1998) provided a relative weight equation for shovelnose sturgeon throughout its range to calculate relative weight and is reported as follows:

$$\log_{10}W = -6.287 + 3.330 \log_{10}FL.$$

Mean Wr values were compared for age 1, 2, and 3 shovelnose sturgeon by river segment for each year. River segments were grouped into an upper and lower sampling universe to determine if condition varied spatially.

Mean monthly river temperature (°C) and mean monthly discharge (m^3/s) was calculated for each river segment during 2003-2006. These calculations are depicted in Figures 2-12 and are intended to assist in interpretation of spatial growth patterns and variability in recruitment. It is assumed that growth is slower in the upper universe due to colder temperatures which slows metabolism and limits activity. In addition, large pulses in the hydrograph during the spring time are thought to trigger spawning cues and inundate flood plains that ultimately may lead to increased larval and juvenile production.

Table 1. Segment information for the Missouri River.

Segment Number	Segment Description	Upper River Mile	Lower River Mile	Length (mi)
1	Fort Peck Dam to the confluence of the Milk River	1771.5	1760.0	11.5
2	Confluence of the Milk River to Wolf Point	1760.0	1701.0	59.0
3	Wolf Point to the confluence of the Yellowstone River	1701.0	1582.0	119.0
4	Confluence of the Yellowstone River to the headwaters of Lake Sakakawea	1582.0	1568.0	14.0
5	Fort Randall Dam to the confluence of the Niobrara River	880.0	845.0	35.0
6	Confluence of the Niobrara River to the headwaters of Lewis and Clark Lake	845.0	825.0	20.0
7	Gavins Point Dam to Lower Ponca Bend	811.0	750.0	61.0
8	Lower Ponca Bend to the confluence of the Platte River	750.0	595.0	155.0
9	Confluence of the Platte River to the confluence of the Kansas River	595.0	367.5	227.5
10	Confluence of the Kansas River to the confluence of the Grand River	367.5	250.0	117.5
13	Confluence of the Grand River to the confluence of the Osage River	250.0	130.0	120.0
14	Confluence of the Osage River to the confluence with the Mississippi River	130.0	0.0	130.0

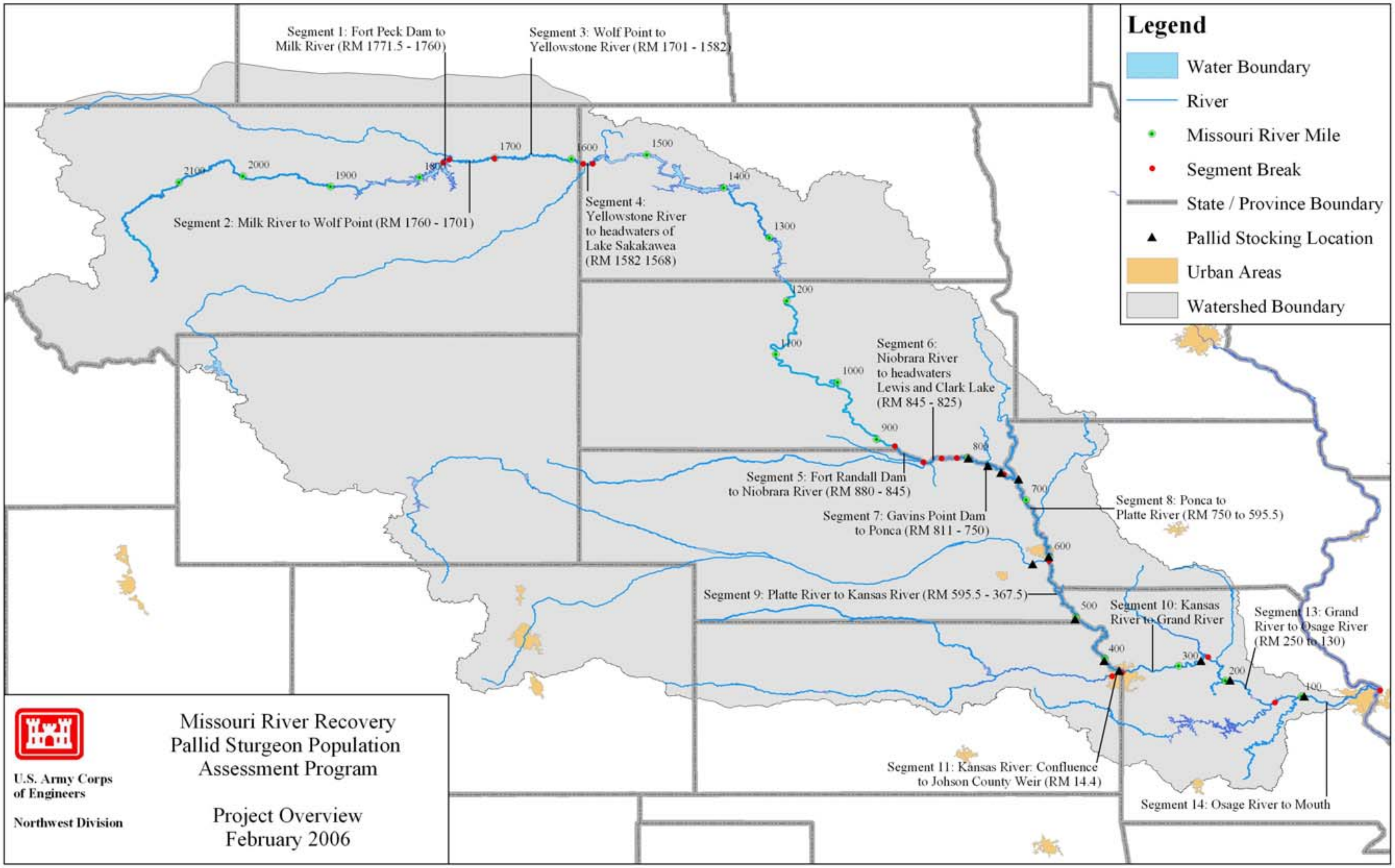


Figure 1. Map of the Missouri River basin with locations of major tributaries and urban areas. Study segments are numbered, labeled and delimited by red dots.

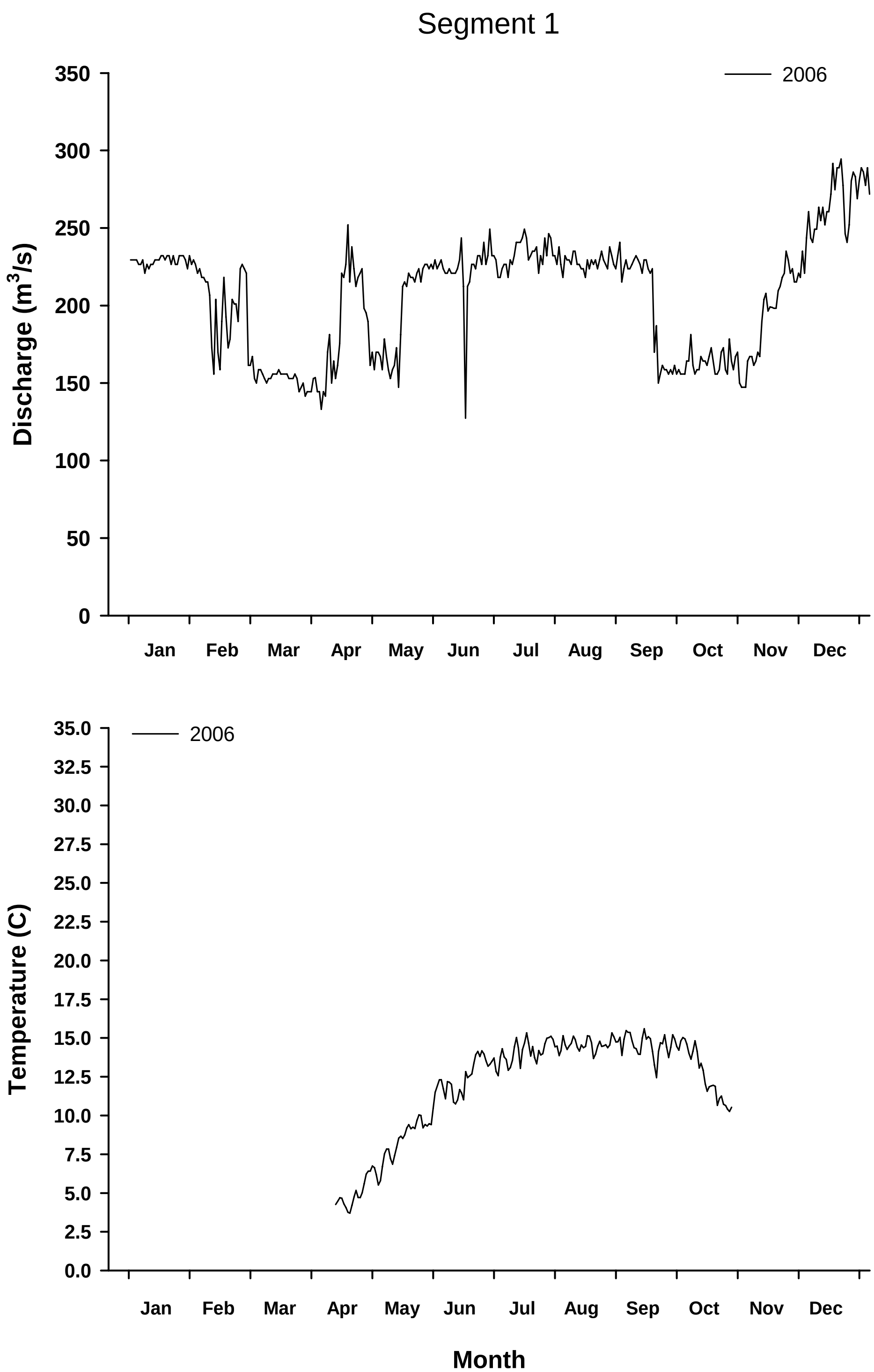


Figure 2. Mean daily discharge and mean daily water temperature for segment 1 of the Missouri River during 2006

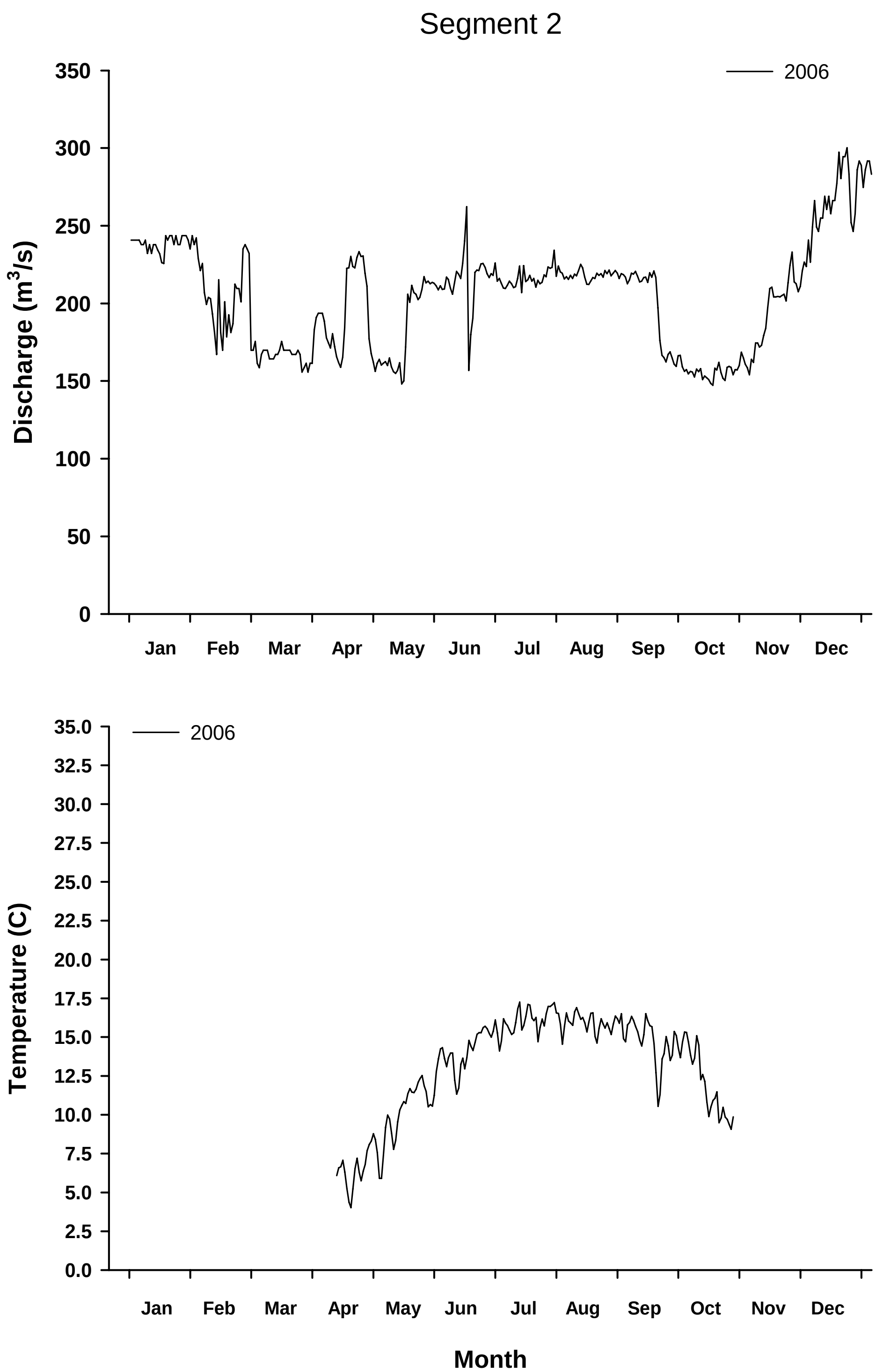


Figure 3. Mean daily discharge and mean daily water temperature for segment 2 of the Missouri River during 2006

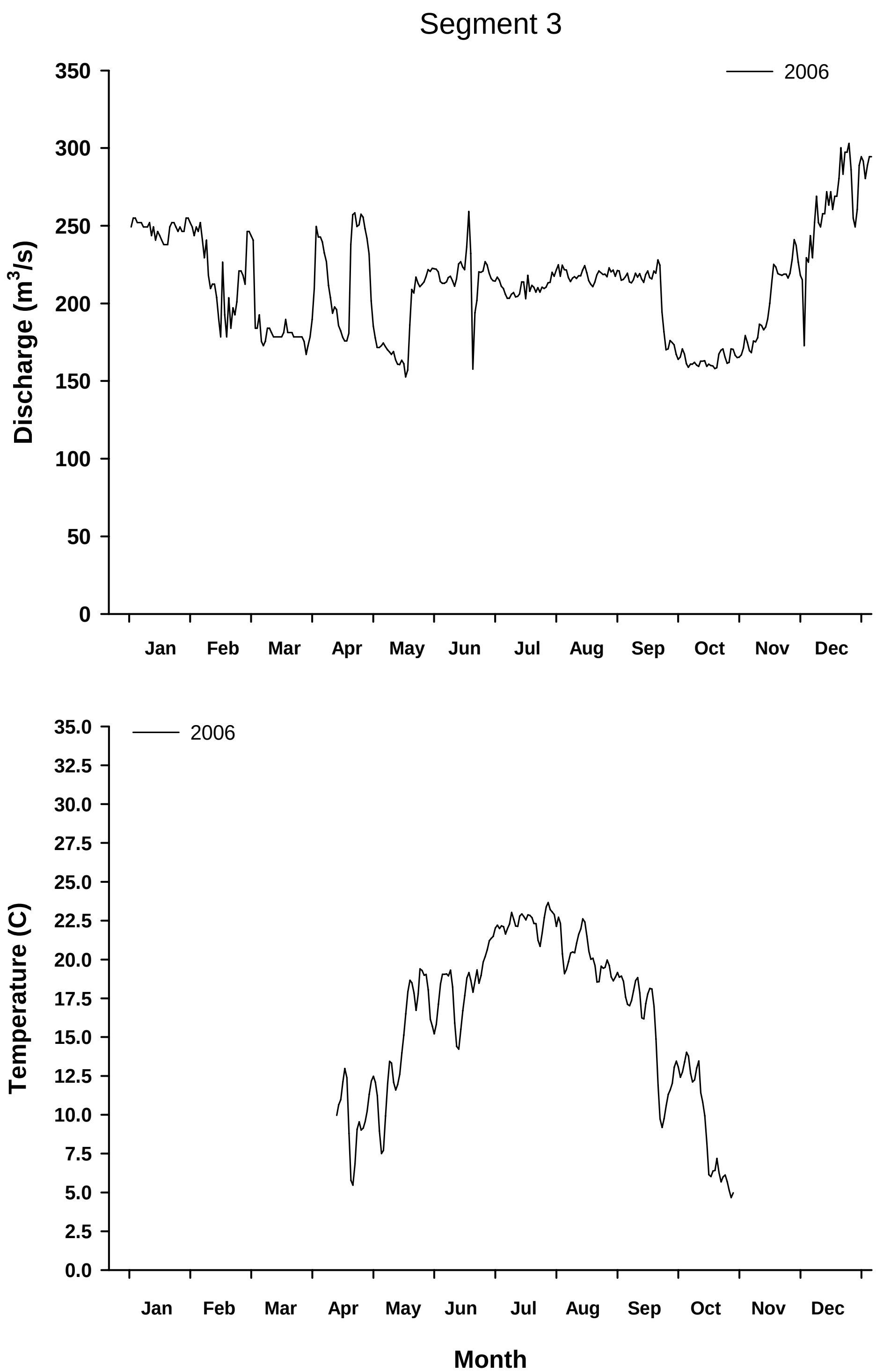


Figure 4. Mean daily discharge and mean daily water temperature for segment 3 of the Missouri River during 2006

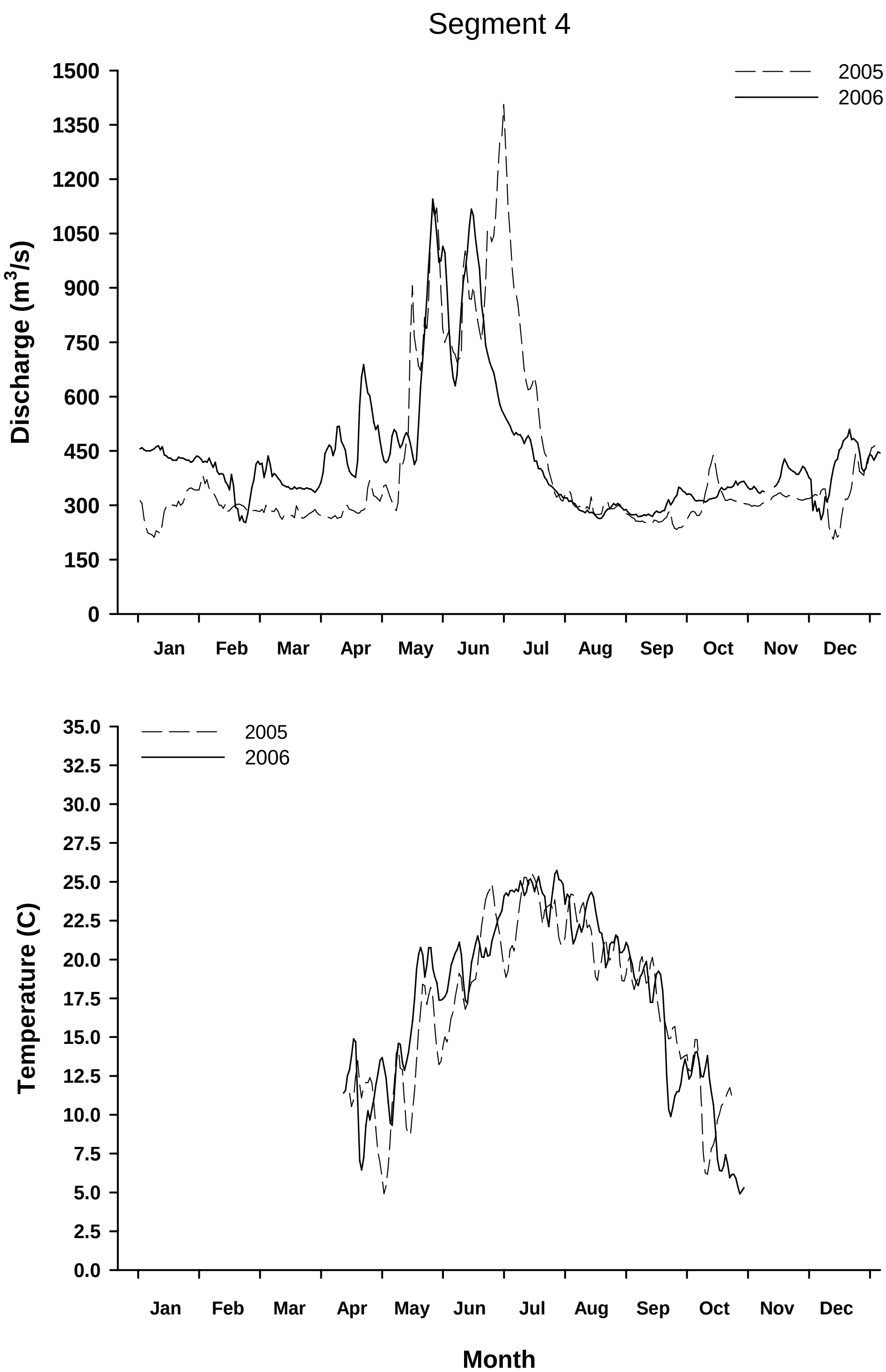


Figure 5. Mean daily discharge and mean daily water temperature for segment 4 of the Missouri River during 2005 and 2006.

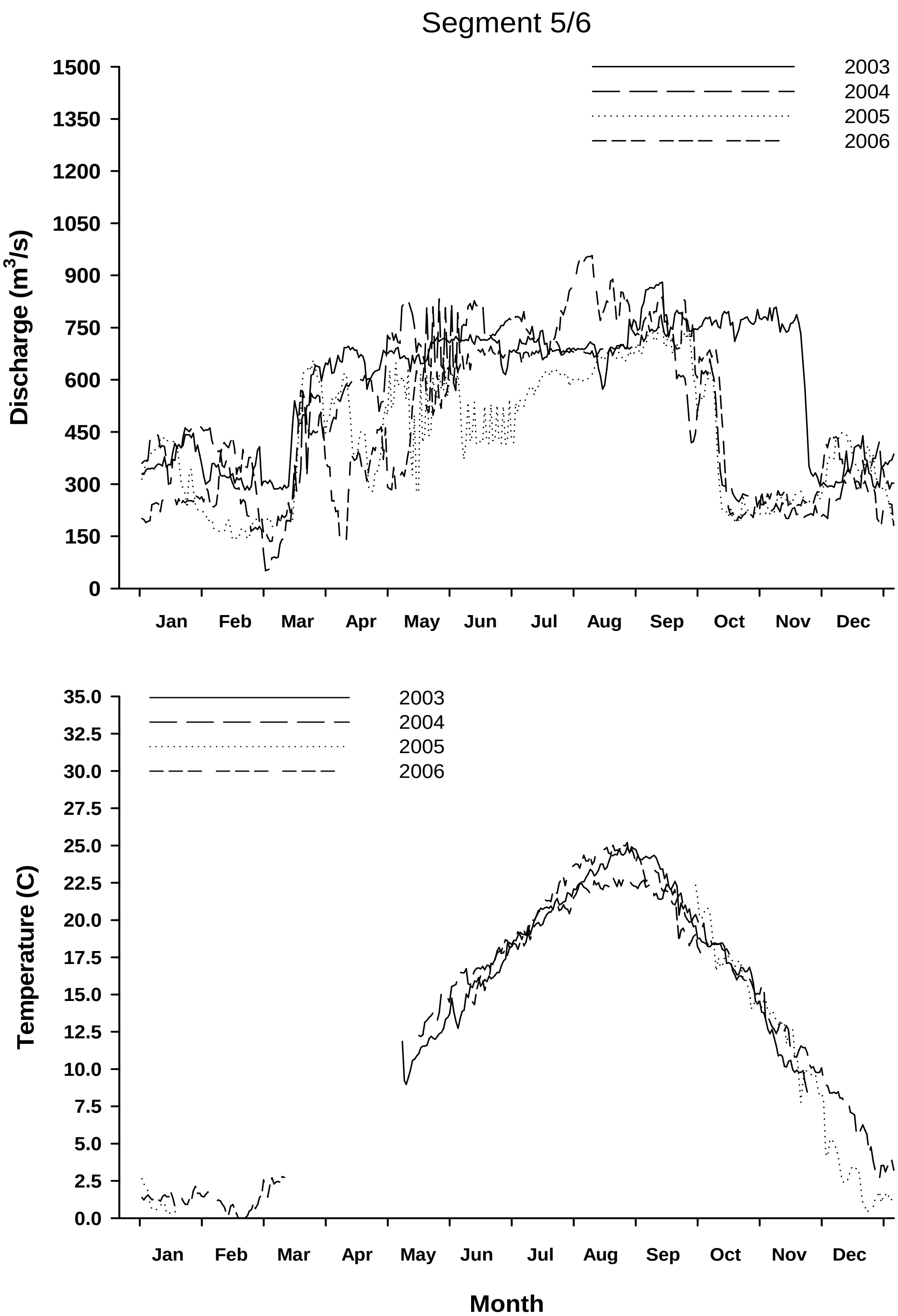


Figure 6. Mean daily discharge and mean daily water temperature for segment 5/6 of the Missouri River during 2003 through 2006.

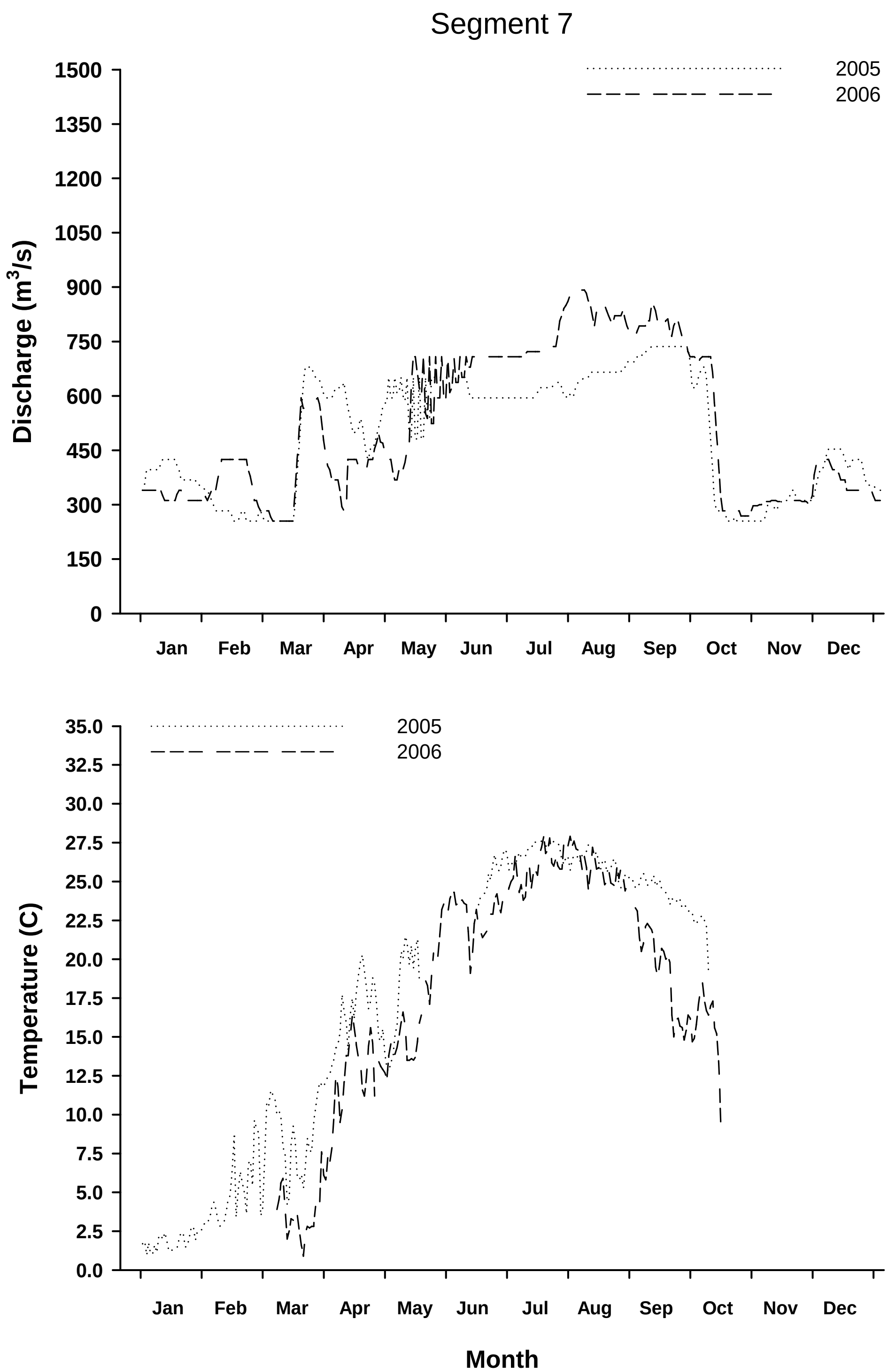


Figure 7. Mean daily discharge and mean daily water temperature for segment 7 of the Missouri River during 2005 and 2006.

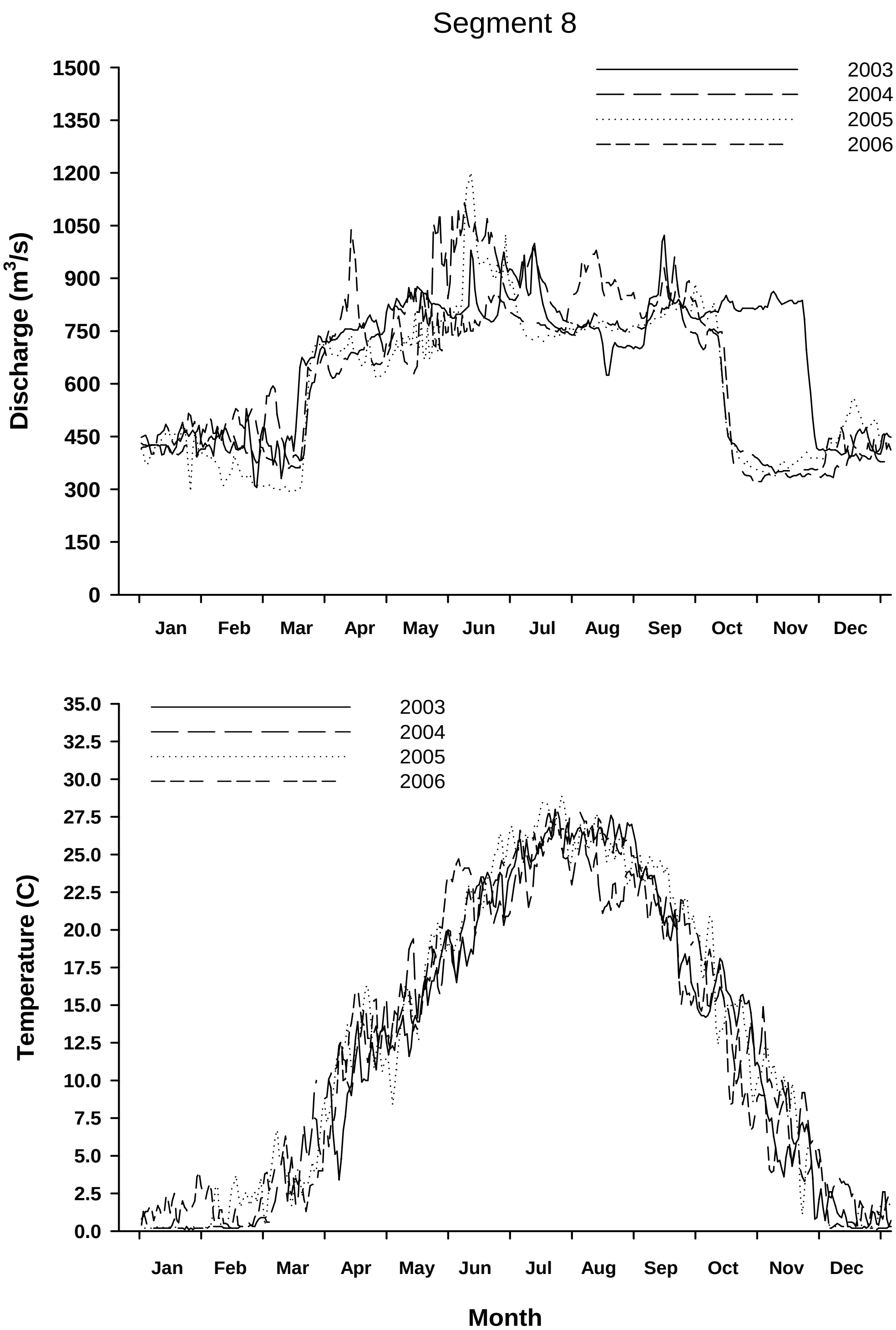
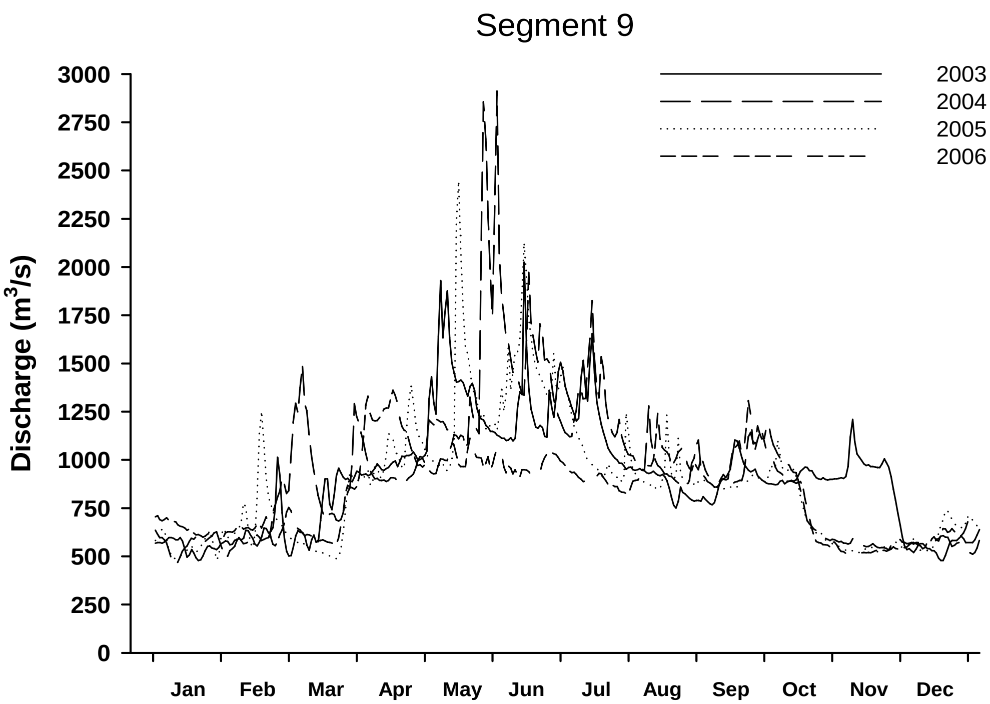


Figure 8. Mean daily discharge and mean daily water temperature for segment 8 of the Missouri River during 2003 through 2006.



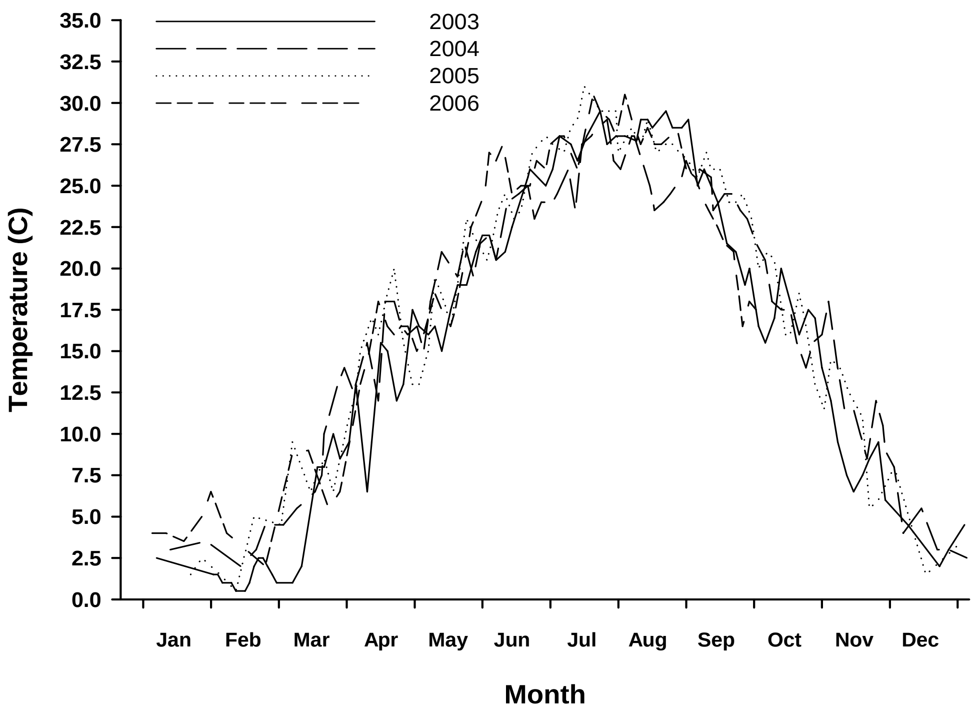


Figure 9. Mean daily discharge and mean daily water temperature for segment 9 of the Missouri River during 2003 through 2006.

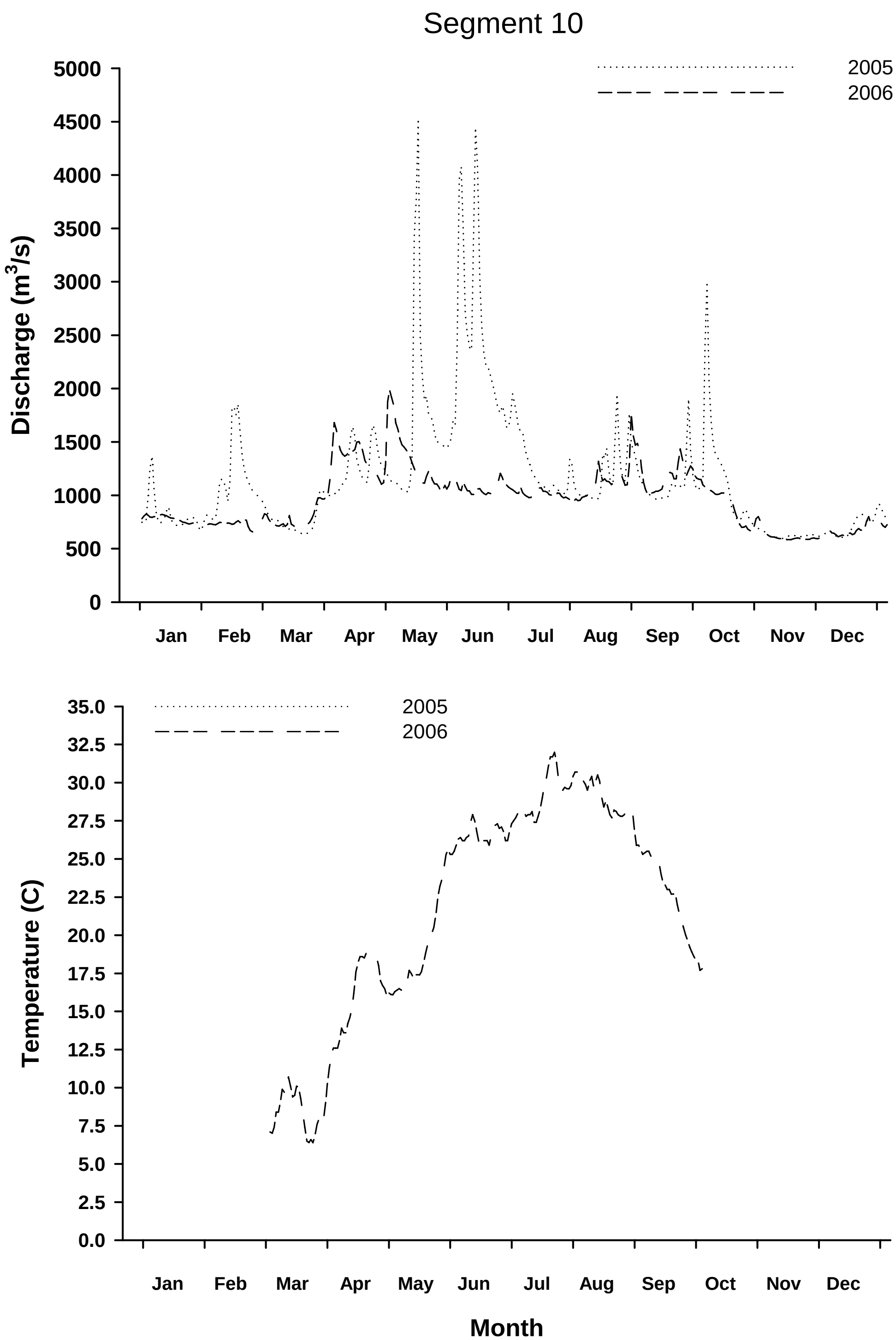


Figure 10. Mean daily discharge and mean daily water temperature for segment 10 of the Missouri River during 2005 and 2006.

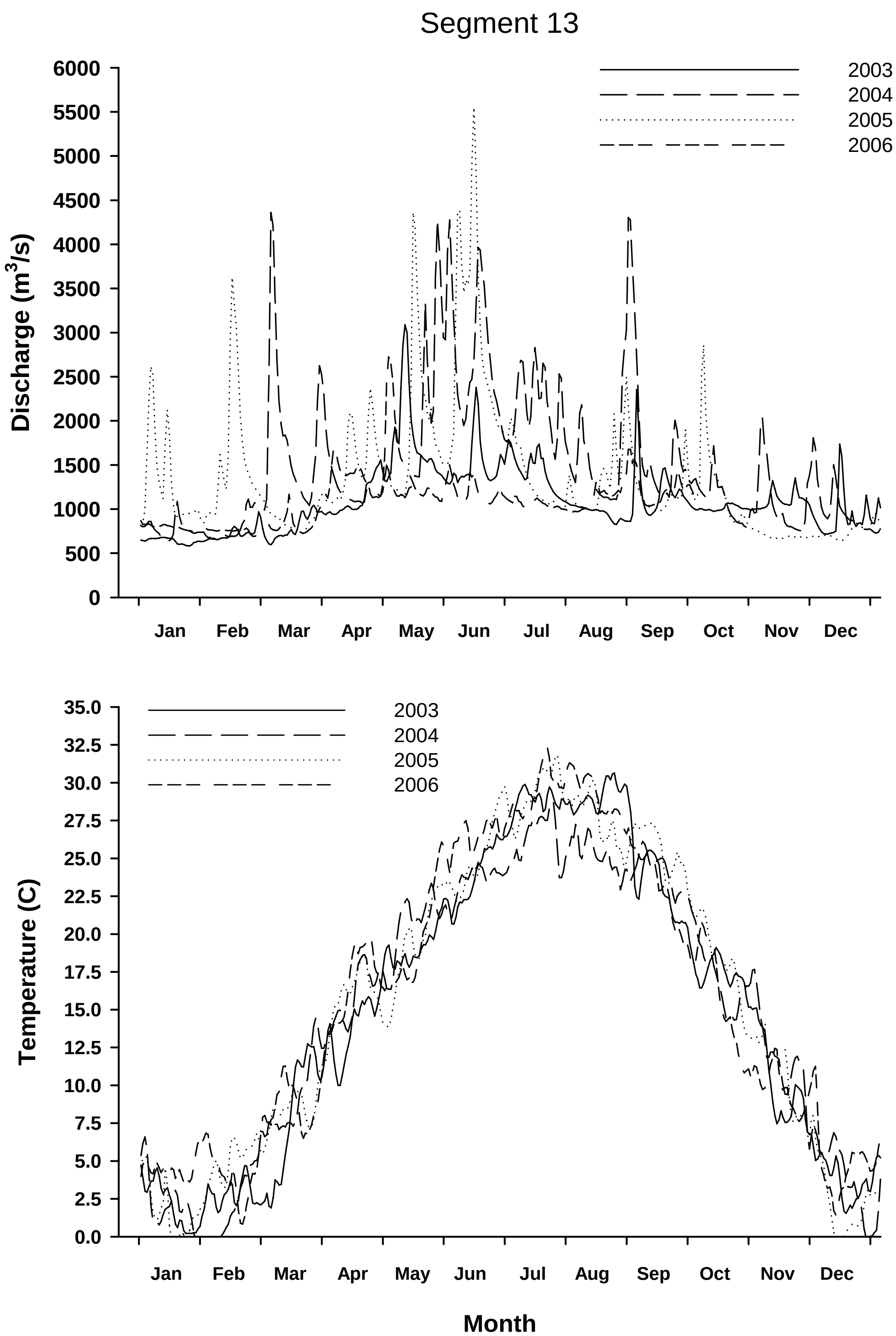


Figure 11. Mean daily discharge and mean daily water temperature for segment 13 of the Missouri River during 2003 through 2006.

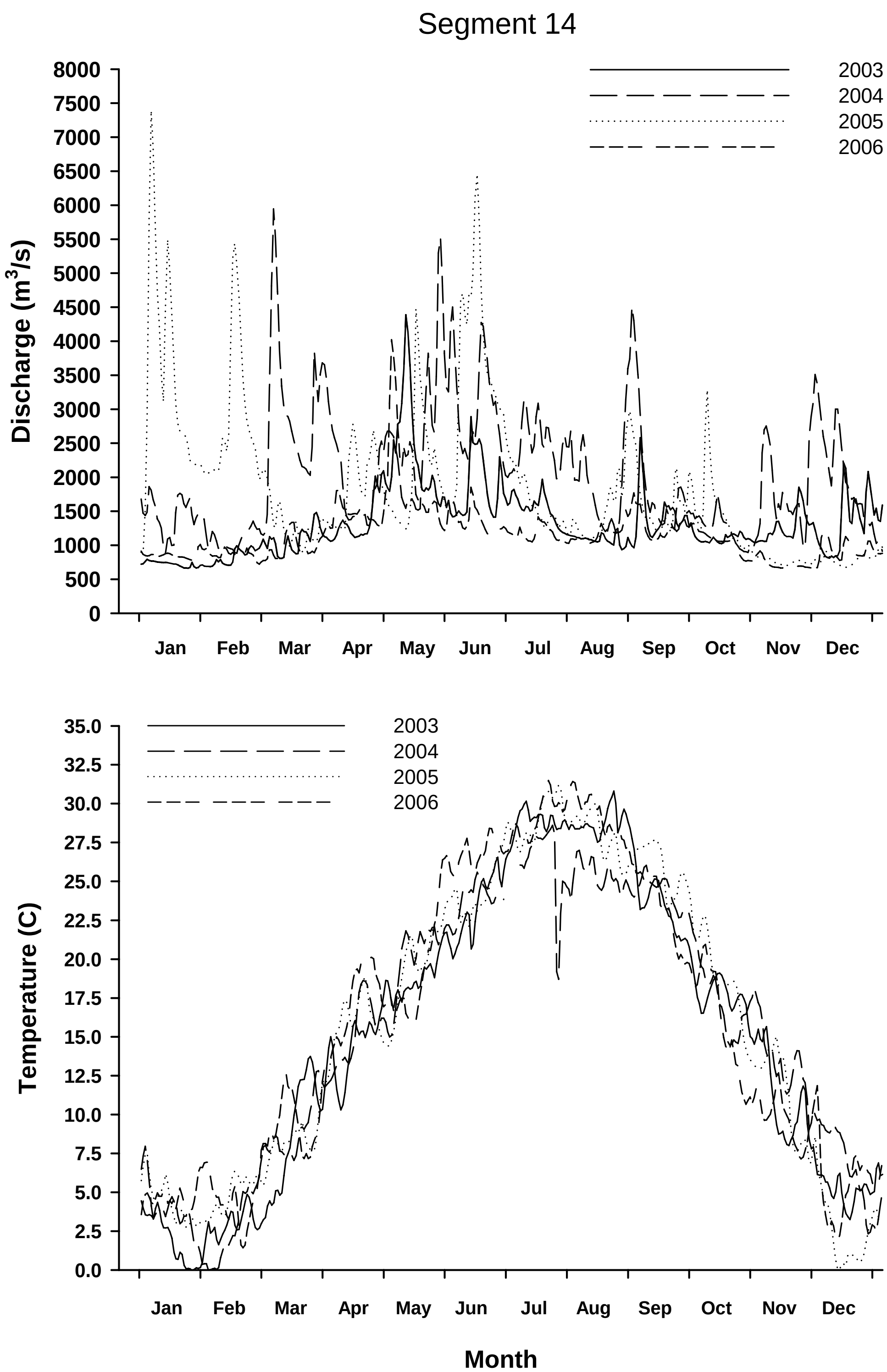


Figure 12. Mean daily discharge and mean daily water temperature for segment 14 of the Missouri River during 2003 through 2006.

Table 2. Starting and ending date by year when aging structures of shovelnose sturgeon were collected.

Year	Starting Date	Ending Date	Segments
2003	November 2003	April 2004	9, 13 and 14
2004	July 2004	March 2005	9, 13 and 14
2005	July 2005	April 2006	4, 7, 8, 9, 10, 13 and 14
2006	July 2006	April 2007	1, 2, 3, 4, 7, 8, 9, 10, 13 and 14

Results

A total of 2,602 shovelnose sturgeon fin rays were collected for age and growth analysis (Table 3). During 2003 and 2004, the USFWS Great Plains Fish and Wildlife Management Assistance Office (Pierre, SD; segments 5 and 6), the Nebraska Game and Parks Commission (segment 9) and the USFWS Fisheries Resource Office (Columbia, MO; segments 13 and 14) were the only three agencies contracted under the Pallid Sturgeon Population Assessment Project. Shovelnose sturgeon under 530-mm are rarely collected in segments 5 and 6; therefore, no aging structures were included in this analysis. There were 333 and 335 aging structures collected from shovelnose sturgeon from segments 9, 13 and 14 in 2003 and 2004, respectively. The USFWS Missouri River Fish and Wildlife Management Assistance Office (Bismarck, ND; Segment 4), the South Dakota Game, Fish and Parks (segment 7), the Nebraska Game and Parks Commission (segment 8) and the Missouri Department of Conservation (segments 10 and 11) started sampling in 2005, resulting in a total collection of 945 fin rays. Basin wide sampling began in 2006 when Montana Fish, Wildlife and Parks was contracted to sample segments 1, 2 and 3. A total of 989 aging structures were collected from the entire Missouri River in 2006.

Mean back-calculated fork length-at-last annulus indicated that shovelnose sturgeon grow rapidly during their first year across the entire Missouri River basin (Tables 4 - 7 and Figures 13 -17). The mean average growth for an age-1 fish for all river segments was 190-mm. As fish grow into their second and third year, mean average growth rates decline to 92-mm and 68-mm, respectively. Between 2003 and 2006, there appeared to be a declining trend in mean fork length-at-last annulus. The mean back-calculated fork length for an age-1 shovelnose sturgeon was 204-mm in 2003; however the mean declined to 198-mm, 187-mm and 185-mm in 2004, 2005 and 2006, respectively. A similar trend was observed for other age classes for all four years. Comparisons between the upper and lower sampling universe displayed nearly identical growth rates for age-1 and age-2 shovelnose sturgeon in 2005 (Figure 18). Conversely, the upper sampling universe displayed growth rates that were 11 - 25-mm higher than the lower sampling universe for age1 - age 6 in 2006.

Comparisons of mean length-at-capture of shovelnose sturgeon collected in 2003 and 2004 revealed no differences between age-2 (2003; F = 0.13, P = 0.756 and 2004; F = 0.44, P = 0.512) or age-3 (2003; F = 0.94, P = 0.392 and 2004; F = 0.59, P = 0.556)(Tables 8 and 9); however, differences were observed for all three age classes in 2005 (age-1; F = 4.53, P = 0.001, age-2; F = 5.53, P = < 0.001 and age-3; F = 7.93, P = < 0.001)(Table 10). Age-1 shovelnose sturgeon appear to be growing the slowest in segment 9 (224-mm) and fastest in segments 8 (319-mm) and 11 (360-mm). Specific differences for mean fork length-at-capture for age-1 (segment 8 and 11 > 9 and 13), age-2 (segment 14 and 13 > 10) and age-3 (segment 7, 8 and 13 > 10, 13 and 14 and segment 9 > 13) appear to follow no particular pattern. Mean fork length-at-capture were similar between segments for age-1 shovelnose sturgeon in 2006 (F = 0.41, P = 0.889) (Table 11); however, differences were observed between mean fork length-at-capture for age-2 (F = 3.03, P = 0.003) and age-3 (F = 5.14, P = < 0.001) fish. Mean length-at-capture for shovelnose sturgeon were compared between the sampling universes for age-1, age-2 and age-3 for all sampling years (Tables 12). There were no differences observed between age-1 (F = 2.53, P = 0.115), age-2 (F = 1.23, P = 0.267) or age-3 (F = 1.11, P = 0.293).

Age-length keys are presented in tables 13 - 24 by individual segments. Age-0 shovelnose sturgeon in the Missouri River were generally less than 179-mm. Lengths for age-1 (180-259 mm), age-2 (260-349 mm), age-3 (350-449 mm) and age-4 (450-530 mm) shovelnose sturgeon were based on the overall mean fork length from all segments and years. Age-3 and age-4 represented over 64% of the age structures collected, while only 16% were greater than age-5.

Additional Analysis

Mean Wr of age-3 shovelnose sturgeon differed among segments (F = 7.03, P = 0.001) in 2003 (Appendix A). There was no further analysis conducted in 2003 due to low sample size of age-1 and age-2 fish. There were no significant differences between segments for all age classes in 2004 (age-2; F = 1.24, P = 0.279 and age-3; F = 0.04, P = 0.961) (Appendix B) and for age-1 and age-2 in 2005 (age-1; F = 1.3, P = 0.282 and age-2; F = 1.74, P = 0.114) (Appendix C). Age-3 shovelnose in 2005 had a significantly higher mean Wr in segment 11 compared to all other segments (F = 3.64, P = 0.0009). As in previous years, mean Wr of age-1 shovelnose sturgeon was similar between segments in 2006 (F = 2.04, P = 0.095) (Appendix D). Differences in mean Wr were observed for age-2 (F = 2.46, P = 0.014; segment 4 > 2 and 9) and age-3 (F = 3.22, P = 0.001; segment 4, 10, 11 and 14 > 2). Mean Wr for shovelnose sturgeon was similar between the sampling universes when all years were combined (Appendix E). There were no differences between age-1 (F = 3.24, P = 0.076) or age-3 (F = 2.49, P = 0.115); however, age-2 shovelnose sturgeon (F = 13.73, P = 0.0002) in the upper sampling universe had a higher Wr.

Mean back-calculated fork length-at-last annulus was calculated under the assumption that variation between years was minimal and that growth variation was a function of spatial differences along the Missouri River. Our results indicated that there were substantial differences between years (Appendix G); therefore, back-calculation procedures were modified for an additional analysis. Back-calculated ages were assigned a year class (2000, 2001, 2002 and 2003) based on year of birth. These year classes were then compared across segments to determine differences in growth by year. Results indicated that there were significant differences in growth between segments for age-1 and age-2 shovelnose sturgeon in the 2000, 2001 and 2003 year classes; however, no differences were observed in the 2002 year class (Appendix H - J). Age-3 shovelnose sturgeon displayed significant differences between segments for all of the various year classes.

Specific comparisons revealed that there were no differences in growth between segments in the upper sampling universe (i.e., segments 1-4) for age-1-3 shovelnose sturgeon. In the lower sampling universe, growth rates were the slowest in the 2000 year class and progressively increased each year after, except for segment 9. Growth in segment 9 remained fairly consistent across year classes and the best observed growth was in the 2001 year class. Growth rates for age-3 shovelnose sturgeon were not as clearly defined. Generally, the best growth rates were achieved within the 2002 and 2003 year classes while the 2000 year class remained as the slowest (Appendix K – M).

Table 3. Total number of aging structures collected for age and growth analysis.

Length	Overall Total	2003				2004				2005								
		9	13	14	Total	9	13	14	Total	4	7	8	9	10	11	13	14	Total
130	**1**													1				**1**
140	**1**													1				**1**
150	**1**																	
160	**2**																	
170	**0**																	
180	**1**																	
190	**7**												1			1		**2**
200	**9**												1			1	1	**3**
210	**5**									1				2		1		**4**
220	**9**									1			3			2	1	**7**
230	**10**									1				2		3	2	**8**
240	**10**													2		5	2	**9**
250	**18**													3		6	4	**13**
260	**20**		1		**1**		1		**1**					4		4	4	**12**
270	**17**												1	2		3	4	**10**
280	**18**		1		**1**								1	3		1	2	**7**
290	**12**													2			1	**3**
300	**14**									1			1	2		3	1	**8**
310	**25**		1		**1**							1	1	5		3		**10**
320	**32**	2	2		**4**			1	**1**	2		2	6	5			2	**17**
330	**35**	2	2	1	**5**	1			**1**	2			5	3		2	3	**15**
340	**34**	1			**1**		1		**1**	1			1			4	4	**10**
350	**49**	1	5	3	**9**	2	3	3	**8**				1	7		5	3	**16**
360	**58**	2	6	3	**11**		3	1	**4**	1			1	3	1	3	10	**19**
370	**51**	3	6	2	**11**		2	2	**4**	1			2	3		6	8	**20**
380	**51**	5	3		**8**		3	1	**4**	3		1		2		7	4	**17**
390	**63**	5	3	1	**9**	2	4	3	**9**	2				8		9	4	**23**
400	**104**	7	2	4	**13**	2	7	6	**15**				1	5	1	9	16	**33**
410	**104**	10	5	1	**16**	8	6	3	**17**			1	4	3		12	12	**32**
420	**116**	1	2	1	**4**	3	6	8	**17**	1		1	6	12		15	13	**47**

Table 3. Continued

Length	Overall Total	2003				2004				2005								
		9	13	14	Total	9	13	14	Total	4	7	8	9	10	11	13	14	Total
430	**148**	8	4	2	**14**	7	6	6	**19**			2	9	12		11	16	**50**
440	**140**	10	8	5	**23**	8	8	6	**22**			1	7	14		10	11	**43**
450	**128**	9	9	1	**19**	6	7	2	**15**			3	10	9		6	13	**41**
460	**175**	10	12	10	**32**	9	12	7	**28**		2	2	14	9		11	13	**51**
470	**174**	11	9	6	**26**	10	10	7	**27**		2	8	15	8		11	16	**60**
480	**175**	9	10	5	**24**	10	8	8	**26**	2	8	7	15	11	1	7	13	**64**
490	**188**	10	8	7	**25**	10	10	8	**28**	1	8	8	13	21	1	9	10	**71**
500	**213**	12	11	5	**28**	15	11	10	**36**	1	16	11	13	11		7	10	**69**
510	**188**	10	10	3	**23**	11	7	3	**21**		10	13	10	15	3	10	13	**74**
520	**196**	15	10		**25**	11	13	7	**31**	3	12	10	12	7	1	12	18	**75**

Table 3. Continued

Length	Overall Total	2006											
		1	**2**	**3**	**4**	**7**	**8**	**9**	**10**	**11**	**13**	**14**	**Total**
130	**1**												
140	**1**												
150	**1**										1		**1**
160	**2**							1			1		**2**
170	**0**												
180	**1**							1					**1**
190	**7**				1			1			2	1	**5**
200	**9**				2					1	2	1	**6**
210	**5**											1	**1**
220	**9**				1				1				**2**
230	**10**			1	1								**2**
240	**10**				1								**1**
250	**18**				3							2	**5**
260	**20**				3							3	**6**
270	**17**			1	3						2	1	**7**
280	**18**				5			1	1		1	2	**10**
290	**12**			2					2			5	**9**
300	**14**				1			2				3	**6**
310	**25**				2			3	1	1	1	6	**14**
320	**32**		1					2	2	1	2	2	**10**
330	**35**							6	3		1	4	**14**
340	**34**				4	1		6	2		4	5	**22**
350	**49**		1	2				2	2	2	3	4	**16**
360	**58**			1	1			5	5		7	5	**24**
370	**51**		1	1	1			3	2		4	4	**16**
380	**51**			2	1			4	4		4	7	**22**
390	**63**		2	1				6	5	1	1	6	**22**
400	**104**		7	1	2	1		11	10	2	2	7	**43**
410	**104**		4	1	1	1		9	7	3	4	9	**39**
420	**116**		3	3	1			11	7		9	14	**48**

Table 3. Continued

Length	Overall Total	2006											
		1	**2**	**3**	**4**	**7**	**8**	**9**	**10**	**11**	**13**	**14**	**Total**
430	**148**		4	5	3		5	10	10	3	9	16	**65**
440	**140**	1	3	3	3	1	3	9	7	2	7	13	**52**
450	**128**		2	3			2	14	9	1	10	12	**53**
460	**175**		2	3	3	2	6	11	10	4	12	11	**64**
470	**174**		4	4	5		7	10	10	1	7	13	**61**
480	**175**		2	5	2	2	9	12	8	1	9	11	**61**
490	**188**	1	7	1	1	3	12	9	7	1	7	15	**64**
500	**213**		10	1	3	4	8	21	12	2	10	9	**80**
510	**188**		11	8	1		9	12	11	2	6	10	**70**
520	**196**		6	5	2		9	12	10	6	4	11	**65**

Table 4. Mean back-calculated fork length-at-last annulus (+/- 2 SE) of shovelnose sturgeon collected in each segment during 2003.

Age	Segments 9	Segments 13	Segments 14	Mean
1	204.5 (7.41)	198.1 (9.06)	220.9 (11.18)	204.9 (5.22)
2	292.4 (7.89)	289.6 (9.30)	303.7 (10.88)	293.3 (5.35)
3	359.7 (7.51)	361.8 (8.95)	378.1 (10.99)	363.9 (5.18)
4	419.9 (8.36)	427.1 (10.34)	435.9 (9.65)	425.0 (5.79)
5	440.2 (15.48)	438.5 (27.59)	446.6 (8.51)	440.4 (12.39)
6	455.6 (30.65)			455.6 (30.65)
7				
8				

Table 5. Mean back-calculated fork length-at-last annulus (+/- 2 SE) of shovelnose sturgeon collected in each segment during 2004.

Age	Segments			Mean
	9	13	14	
1	245.4 (9.65)	169.4 (9.90)	180.8 (13.71)	198.6 (7.29)
2	327.9 (9.28)	270.4 (11.52)	282.1 (13.51)	293.3 (7.12)
3	394.5 (8.29)	347.3 (11.3)	353.6 (14.90)	366.7 (6.87)
4	438.1 (9.32)	394.1 (13.16)	392.6 (18.39)	412.4 (8.04)
5	463.3 (16.69)	424.2 (15.3)	426.0 (32.51)	434.7 (12.55)
6		424.5	438.0 (31.75)	433.5 (20.41)
7				
8				

Table 6. Mean back-calculated fork length-at-last annulus (+/- 2 SE) of shovelnose sturgeon collected in each segment during 2005.

Age	Segment 4	Segment 7	Segment 8	Segment 9	Segment 10	Segment 11	Segment 13	Segment 14	Mean
1	181.4 (23.80)	178.3 (15.09)	191.9 (11.54)	186.5 (8.21)	168.4 (8.14)	227.2 (29.14)	190.0 (8.02)	201.2 (8.23)	187.3 (3.77)
2	286.2 (25.02)	280.9 (16.21)	299.3 (12.13)	293.3 (8.80)	260.1 (9.47)	353.6 (16.20)	288.8 (9.10)	304.7 (8.71)	288.2 (4.20)
3	377.2 (32.12)	357.6 (17.56)	381.8 (11.94)	369.0 (9.17)	334.6 (10.58)	449.5 (18.96)	352.2 (10.30)	364.6 (8.79)	358.6 (4.54)
4	411.3 (49.75)	403.5 (17.52)	422.5 (14.50)	411.3 (10.55)	382.9 (11.74)		400.0 (13.73)	411.5 (11.75)	402.6 (5.46)
5	439.5 (53.73)	425.4 (18.10)	457.4 (25.53)	423.7 (23.21)	404.5 (14.71)		415.3 (29.54)	451.8 (20.81)	424.8 (9.07)
6	474.8 (40.53)	462.1 (18.86)	465.7	459.5 (21.80)	467.6 (15.20)		409.0 (46.57)	476.4 (26.50)	459.2 (12.30)
7				453.0	490.3		438.1		460.5 (31.01)
8							476.5		476.5

Table 7. Mean back-calculated fork length-at-last annulus (+/- 2 SE) of shovelnose sturgeon collected in each segment during 2006.

Age	**Segments**											**Mean**
	1	**2**	**3**	**4**	**7**	**8**	**9**	**10**	**11**	**13**	**14**	
1	209.9 (10.78)	204.5 (11.52)	207.5 (14.69)	178.1 (16.96)	188.0 (26.72)	197.6 (11.45)	184.4 (6.48)	184.3 (8.03)	196.4 (17.29)	175.9 (8.37)	177.0 (7.26)	185.5 (3.24)
2	292.5 (16.25)	293.6 (11.80)	294.2 (15.27)	265.5 (21.28)	276.3 (22.02)	288.9 (10.86)	269.7 (7.05)	268.1 (8.18)	282.4 (16.09)	253.6 (9.13)	250.7 (7.85)	268.2 (3.49)
3	346.7 (1.89)	349.7 (11.76)	348.9 (16.58)	351.4 (27.20)	339.0 (22.60)	364.7 (11.29)	338.8 (7.74)	334.6 (8.68)	346.8 (16.94)	317.3 (10.06)	312.2 (9.11)	333.2 (3.83)
4	392.3 (26.37)	396.3 (15.07)	404.5 (18.47)	403.9 (27.11)	401.5 (19.69)	403.8 (13.18)	387.9 (8.81)	380.2 (9.85)	394.5 (18.55)	359.3 (10.43)	361.6 (11.99)	378.8 (4.67)
5	423.8	413.2 (13.65)	402.9 (29.15)	420.4 (35.65)	440.1 (19.88)	417.0 (12.22)	410.8 (10.70)	403.4 (15.13)	448.5 (22.18)	387.1 (12.95)	390.0 (10.87)	401.3 (5.43)
6		434.0 (12.19)	429.6 (34.12)	462.5	423.4	453.7 (23.13)	429.4 (12.43)	417.1 (21.85)	462.6 (55.91)	407.5 (17.31)	413.8 (11.16)	419.7 (6.69)
7		462.0 (10.18)	450.9 (50.56)			479.9	472.3 (9.62)	464.5 (64.14)		405.4 (19.42)	427.9 (18.32)	442.0 (12.53)
8		484.7	452.4							420.9	487.7	461.4 (31.39)

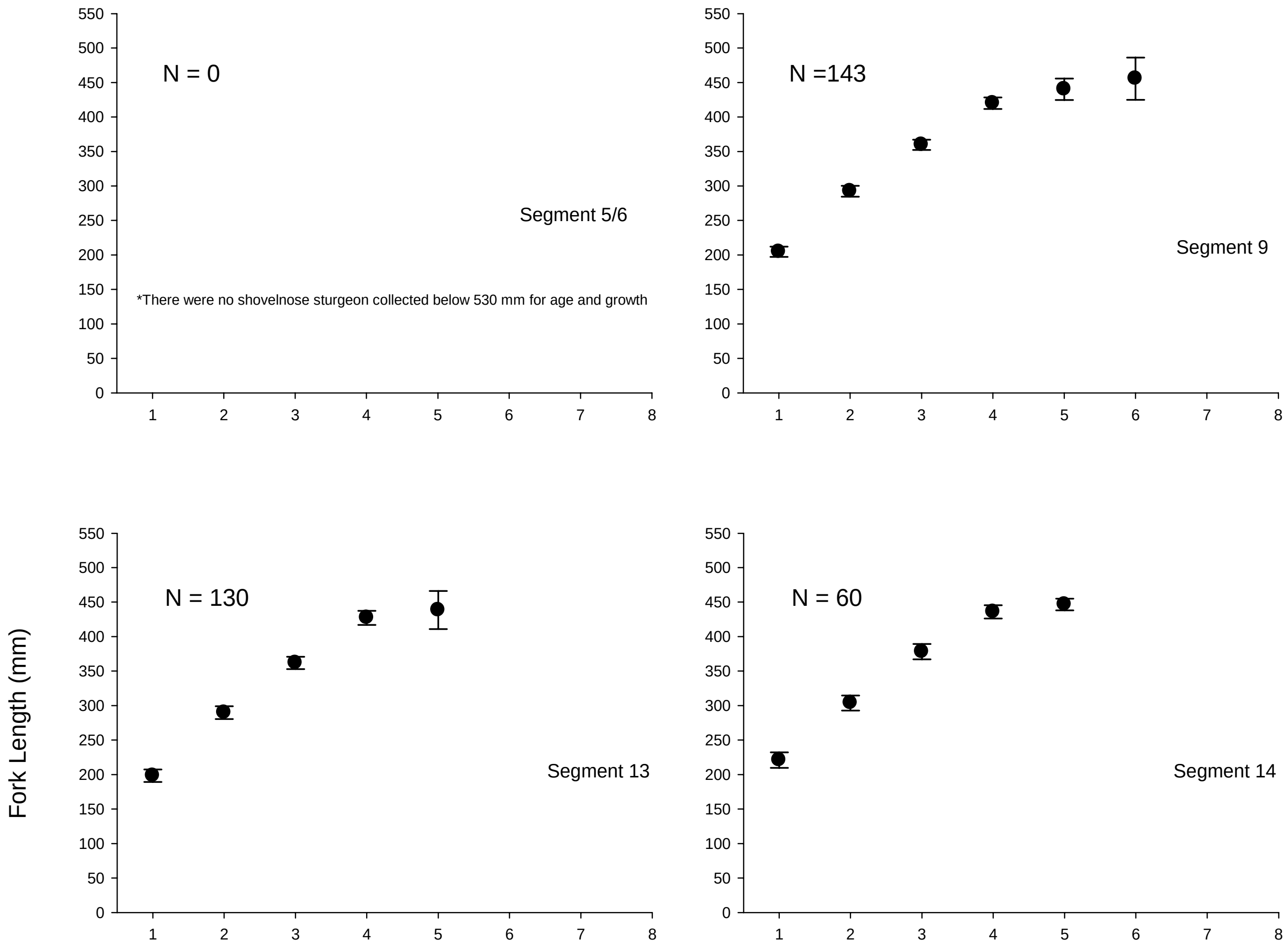


Figure 13. Mean back-calculated fork length-at-last annulus of shovelnose sturgeon that were collected for age and growth analysis from segments 5/6, 9, 13, and 14 of the Missouri River during 2003.

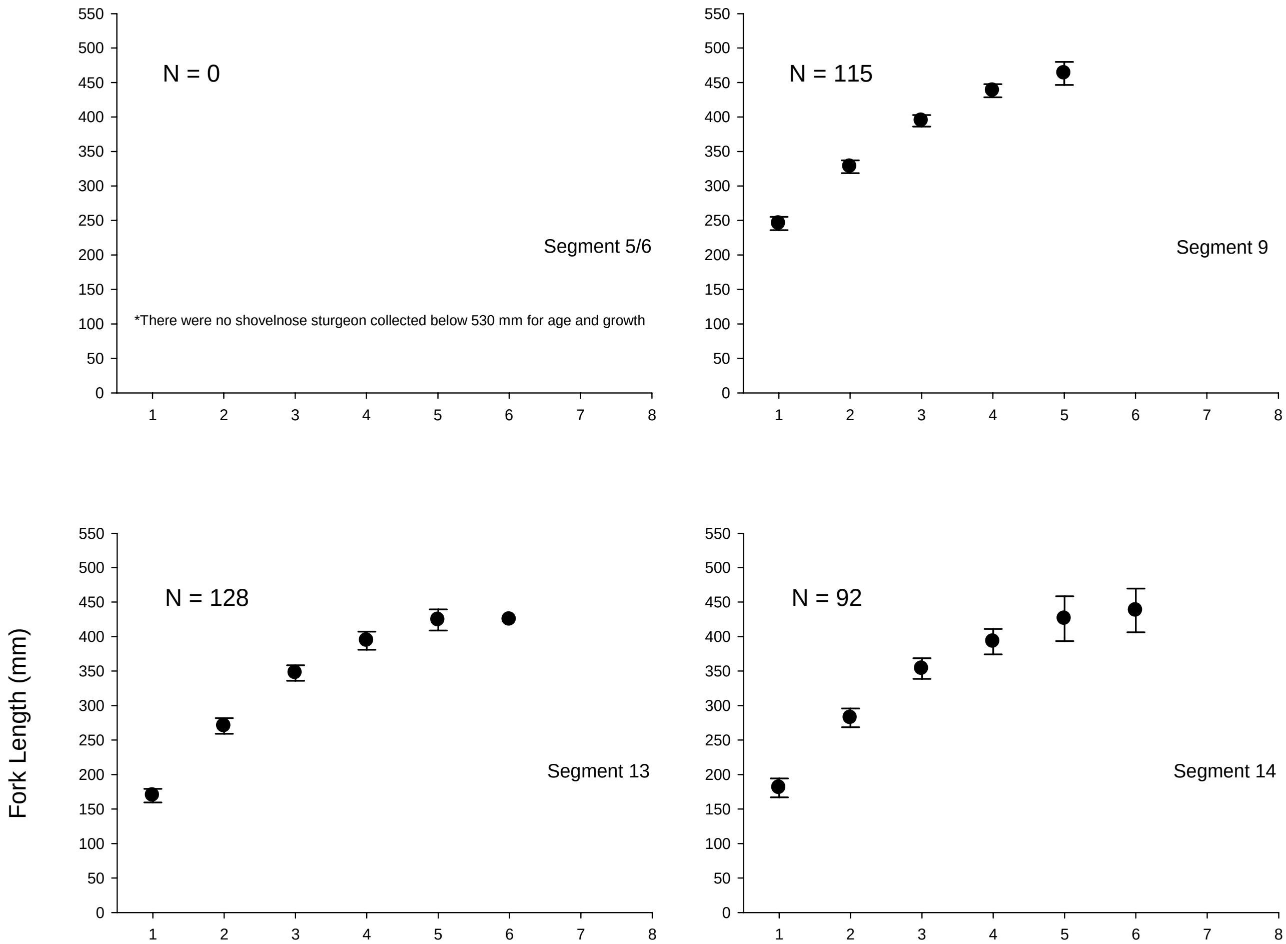


Figure 14. Mean back-calculated fork length-at-last annulus of shovelnose sturgeon that were collected for age and growth analysis from segments 5/6, 9, 13, and 14 of the Missouri River during 2004.

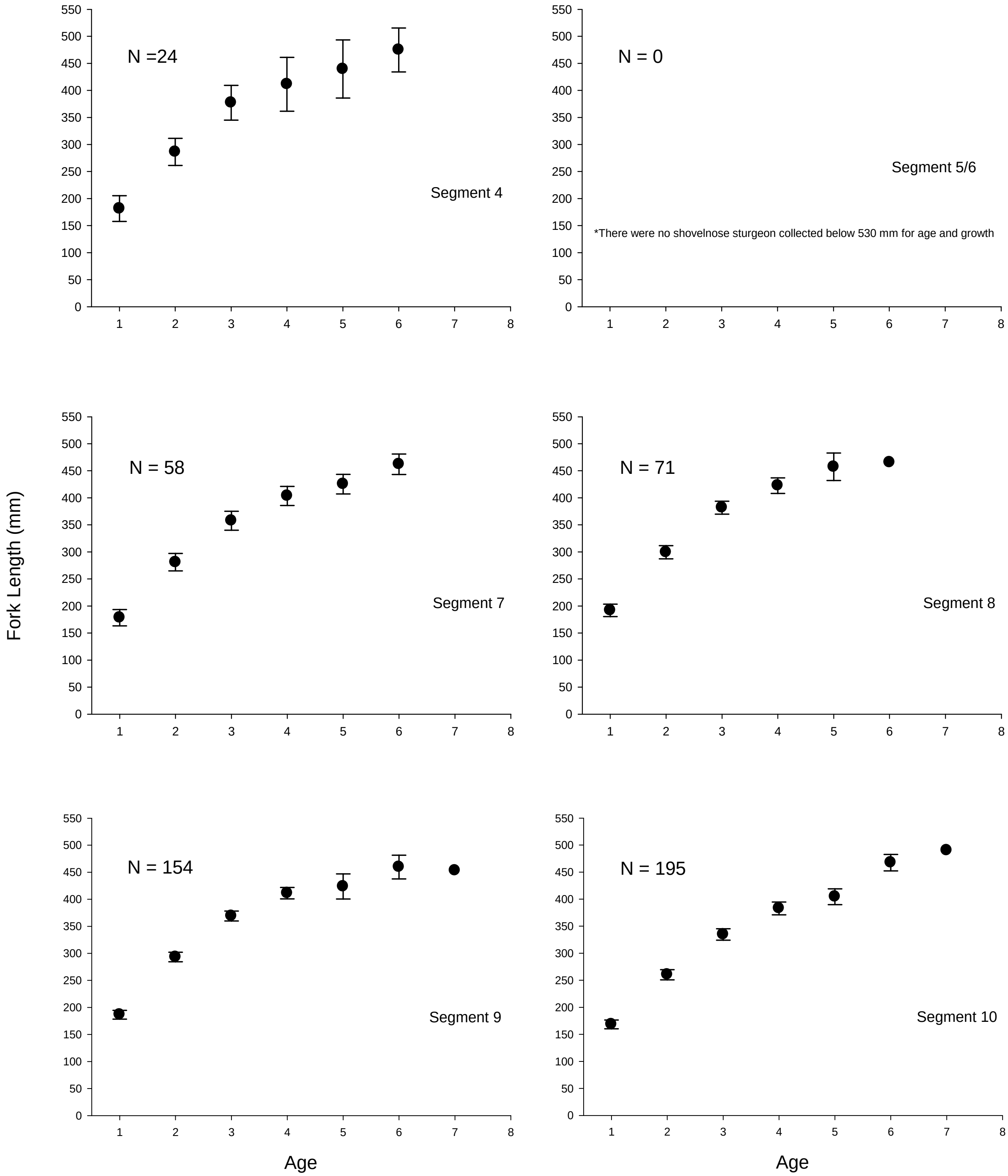


Figure 15. Mean back-calculated fork length-at-last annulus of shovelnose sturgeon that were collected for age and growth analysis from segments 4, 5/6, 7, 8, 9, 10, 13 and 14 of the Missouri River during 2005.

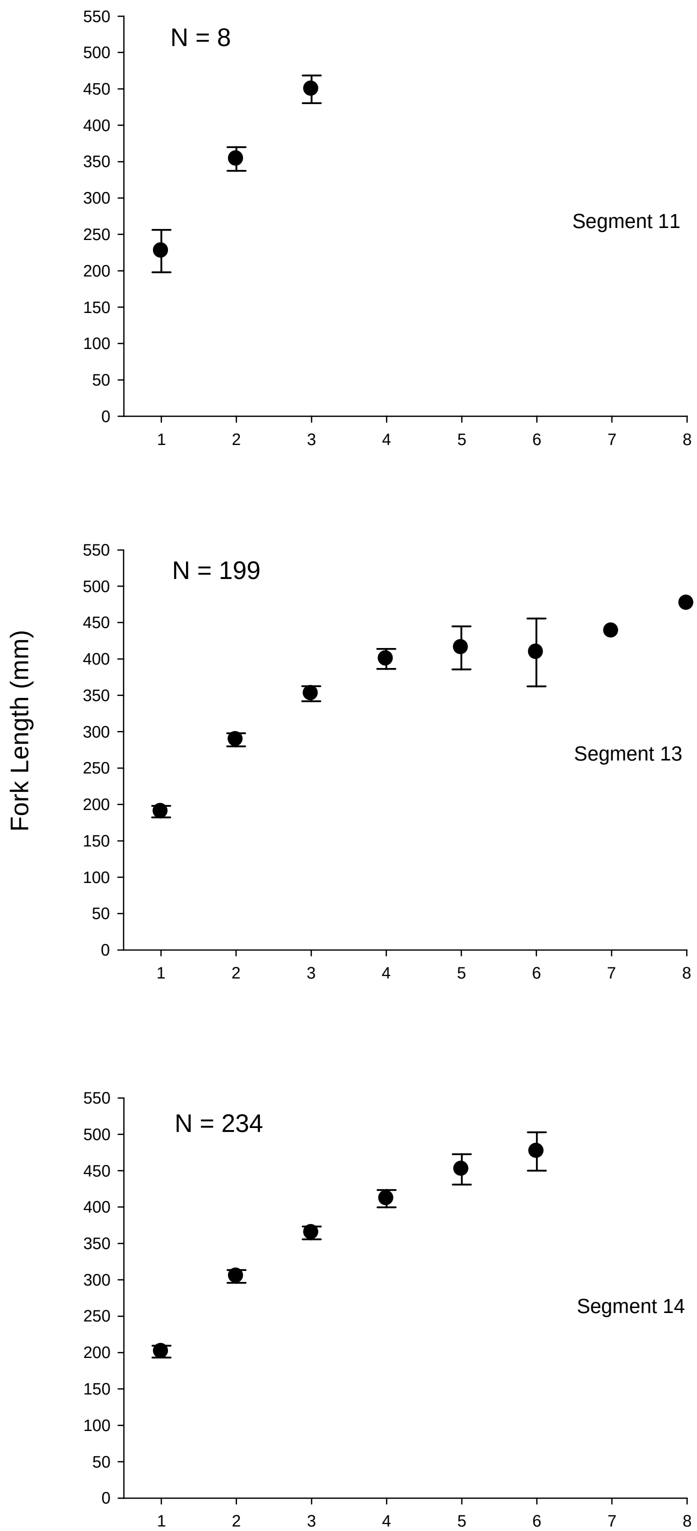


Figure 15. Continued.

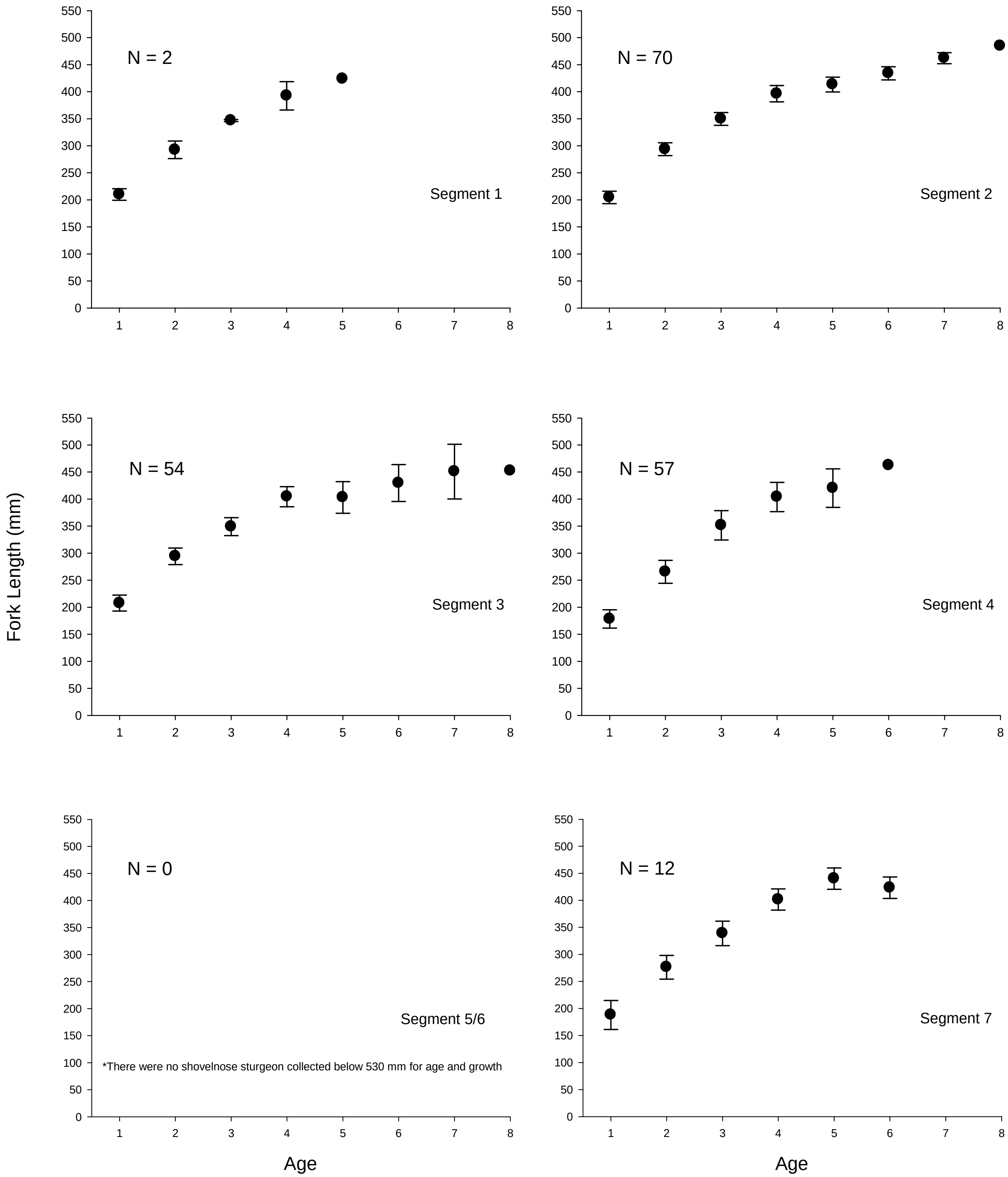


Figure 16. Mean back-calculated fork length-at-last annulus of shovelnose sturgeon that were collected for age and growth analysis from segments 1, 2, 3, 4, 5/6, 7, 8, 9, 10, 11, 13 and 14 of the Missouri River during 2006.

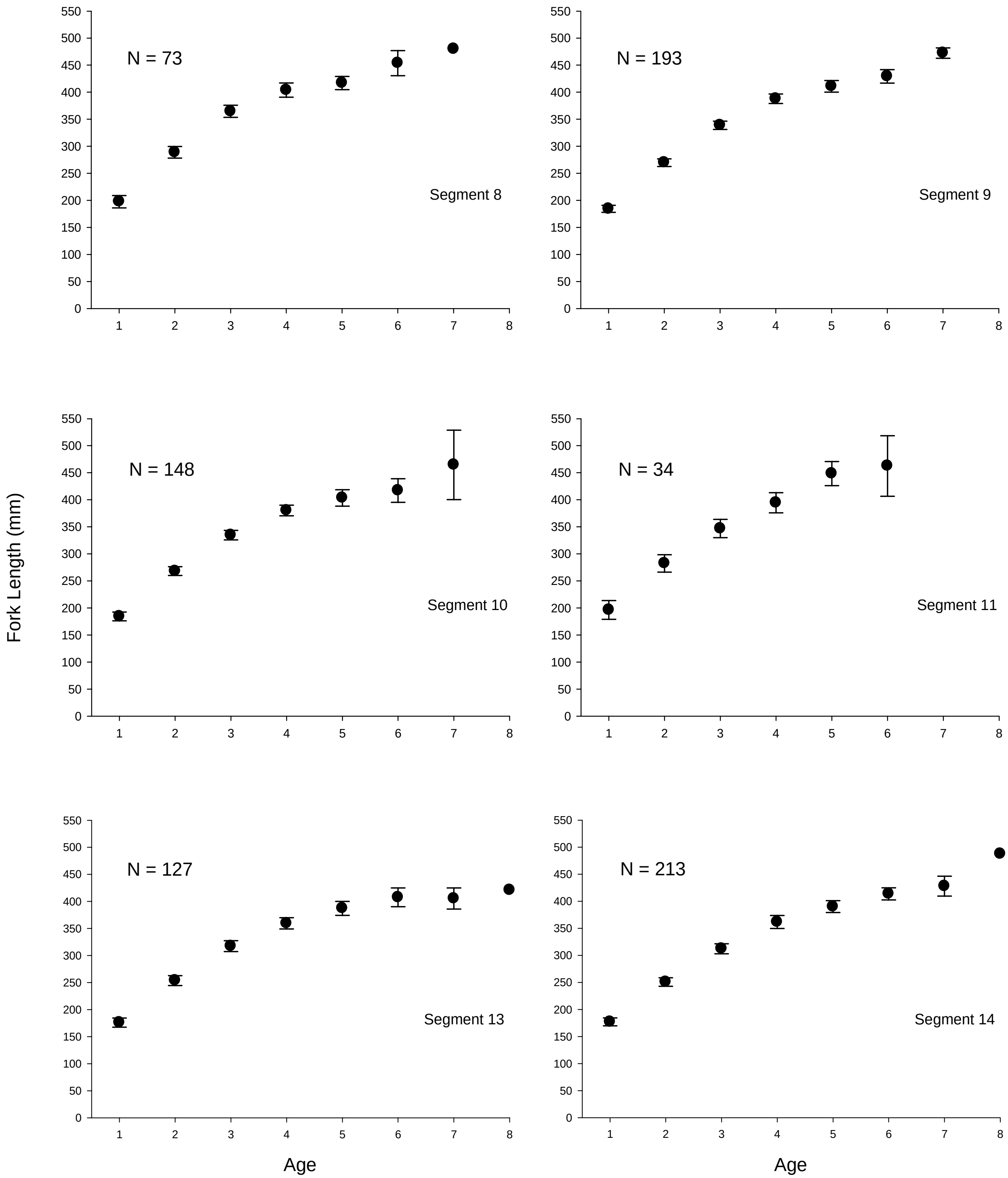


Figure 16. Continued.

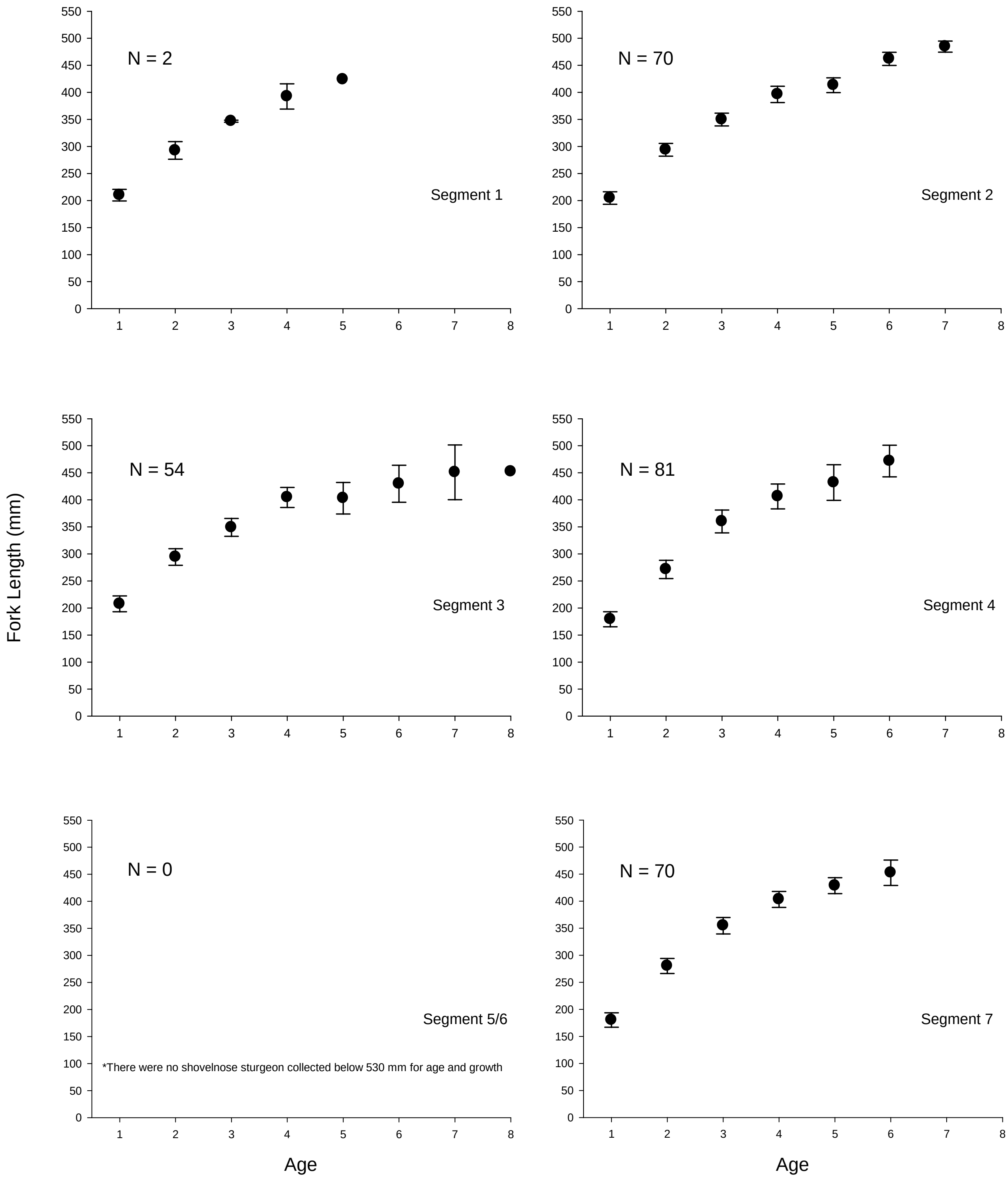


Figure 17. Mean back-calculated fork length-at-last annulus of shovelnose sturgeon that were collected for age and growth analysis from segments 1, 2, 3, 4, 5/6, 7, 8, 9, 10, 11, 13 and 14 of the Missouri River for all years combined.

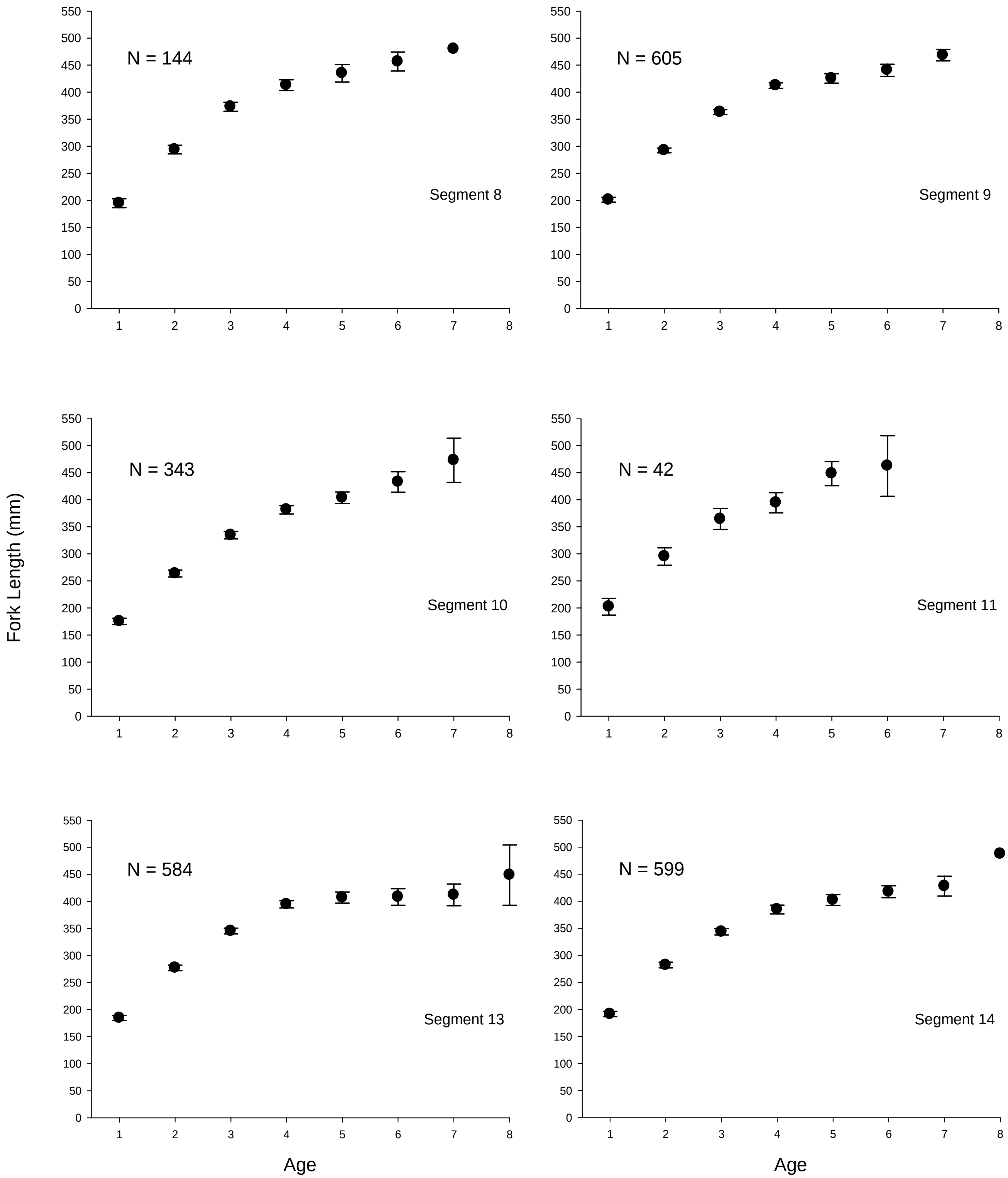


Figure 17. Continued.

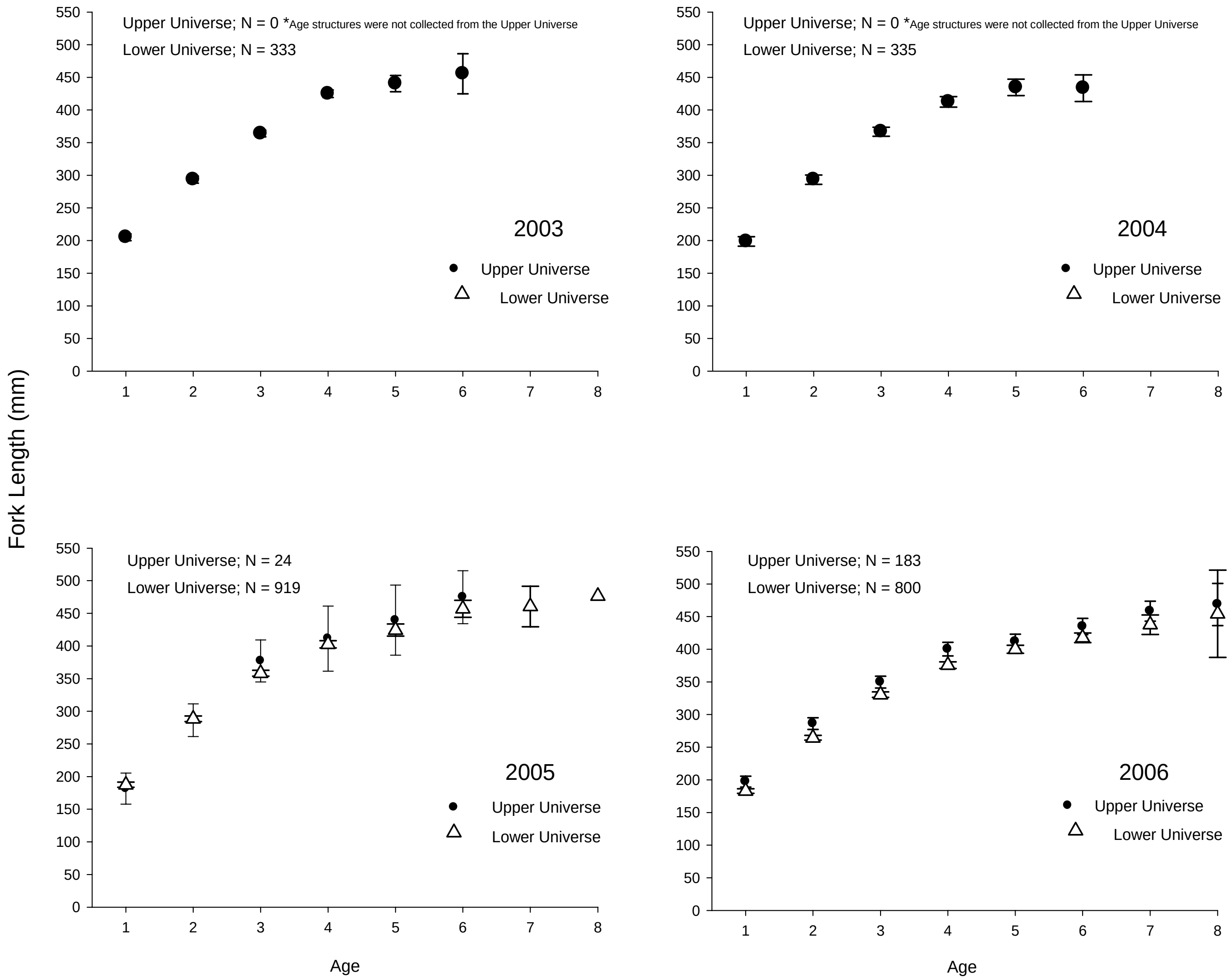


Figure 18. Mean back-calculated fork length-at-last annulus of shovelnose sturgeon that were collected for age and growth analysis from the upper and lower universe of the Missouri River for 2003, 2004, 2005 and 2006.

Table 8. Mean length-at-capture comparisons of shovelnose sturgeon between segments for 2003. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (-) indicate insufficient data to calculate confidence interval. Asterisks indicate ages tested for significant differences among segments. Segment comparisons were done with a one-way ANOVA. Segments sharing a letter indicate no significant differences while different letters indicate significance differences (Tukey's test, alpha = 0.05). Only age-1, age-2 and age-3 were tested for significant differences.

Age	Year Class	Segment		
		9	13	14
0	2003			
1	2002			
2*	2001	320 a -- , 1	358 a 108, 3	
3*	2000	415 a 15, 43	406 a 16, 48	422 a 18, 30
4	1999	475 9, 73	479 8, 64	480 8, 25
5	1998	480 14, 22	479 22, 5	472 16, 5
6	1997	489 19, 4		
7	1996			
8	1995			

Table 9. Mean length-at-capture comparisons of shovelnose sturgeon between segments for 2004. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (-) indicate insufficient data to calculate confidence interval. Asterisks indicate ages tested for significant differences among segments. Segment comparisons were done with a one-way ANOVA. Segments sharing a letter indicate no significant differences while different letters indicate significance differences (Tukey's test, alpha = 0.05). Only age-1, age-2 and age-3 were tested for significant differences.

Age	Year Class	Segment		
		9	13	14
0	2004			
1*	2003			
2*	2002		415 a 14, 53	401 a 20, 17
3*	2001	454 a 14, 44	449 a 14, 53	460 a 14, 39
4	2000	481 8, 63	472 12, 44	474 11, 30
5	1999	492 15, 8	477 11, 16	494 20, 4
6	1998		467 -- , 1	480 38, 2
7	1997			
8	1996			

Table 10. Mean length-at-capture comparisons of shovelnose sturgeon between segments for 2005. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (-) indicate insufficient data to calculate confidence interval. Asterisks indicate ages tested for significant differences among segments. Segment comparisons were done with a one-way ANOVA. Segments sharing a letter indicate no significant differences while different letters indicate significance differences (Tukey's test, alpha = 0.05). Only age-1, age-2 and age-3 were tested for significant differences.

Age	**Year Class**	**Segment**							
		4	**7**	**8**	**9**	**10**	**11**	**13**	**14**
0	2005					140 7, 2			
1*	2004	279 abc 50, 6		319 c 7, 12	224 b 26, 5	253 bc 18, 9	360 ac -- , 1	240 b 11, 17	274 bc 26, 14
2*	2003	357 ab 23, 8		419 ab -- , 1	367 ab 29, 24	336 a 22, 36	408 ab -- , 1	387 b 17, 63	410 b 15, 88
3*	2002	444 ab 41, 6	495 a 7, 12	484 a 11, 33	461 ac 12, 44	437 bc 14, 58	506 a 12, 6	429 b 13, 67	438 bc 11, 79
4	2001	502 -- , 1	506 6, 25	499 8, 26	476 9, 58	465 9, 67		468 15, 41	479 13, 41
5	2000		503 7, 18	509 18, 7	487 15, 16	481 14, 19		492 18, 8	496 18, 10
6	1999	525 3, 3	514 8, 3	494 -- , 1	511 12, 1	512 10, 5		504 12, 2	507 39, 2
7	1998				486 -- , 1	524 -- , 1			
8	1997							518 -- , 1	

Table 11. Mean length-at-capture comparisons of shovelnose sturgeon between segments for 2006. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (-) indicate insufficient data to calculate confidence interval. Asterisks indicate ages tested for significant differences among segments. Segment comparisons were done with a one-way ANOVA. Segments sharing a letter indicate no significant differences while different letters indicate significance differences (Tukey's test, alpha = 0.05). Only age-1, age-2 and age-3 were tested for significant differences.

Age	**Year Class**	**Segment**										
		1	**2**	**3**	**4**	**7**	**8**	**9**	**10**	**11**	**13**	**14**
0	2006							165 -- , 1			182 19, 5	
1*	2005		349 a 59, 2	262 a 61, 2	281 a 36, 12			275 a 58, 6	275 a 94, 2	278 a 155, 2	272 a 82, 3	282 a 24, 14
2*	2004		431 a 26, 9	400 ab 27, 18	336 c 32, 25	440 abc -- , 1	422 abc 39, 5	376 abc 20, 30	364 abc 34, 13	366 abc 68, 3	357 abc 32, 12	351 abc 31, 20
3*	2003		448 ac 17, 25	451 abc 33, 9	446 abc 40, 11	481 abc -- , 1	479 a 11, 32	432 bc 14, 55	433 bc 17, 40	435 abc 30, 12	426 bc 20, 32	401 b 16, 40
4	2002	441 -- , 1	491 19, 15	488 13, 18	484 26, 7	493 16, 4	497 7, 26	469 9, 58	458 12, 59	466 23, 10	445 15, 37	441 13, 60
5	2001	499 -- , 1	496 13, 10	483 35, 3	508 -- , 1	493 14, 5	492 9, 7	479 14, 27	472 16, 21	509 24, 5	471 14, 20	464 16, 37
6	2000		497 13, 5	510 11, 2	529 -- , 1	482 -- , 1	526 4, 2	479 14, 13	461 24, 11	518 16, 2	468 17, 19	472 12, 31
7	1999		518 9, 3	511 -- , 1			497 -- , 1	513 11, 4	516 22, 2		459 45, 3	473 23, 10
8	1998		524 -- , 1	522 -- , 1							496 -- , 1	525 -- , 1

Table 12. Mean length-at-capture comparisons of shovelnose sturgeon between the upper and lower sampling universe. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (-) indicate insufficient data to calculate confidence interval. Asterisks indicate ages tested for significant differences among sampling universes. Sampling universe comparisons were done with a t-test. Sharing a letter indicate no significant differences while different letters indicate significance differences (alpha = 0.05). Only age-1, age-2 and age-3 were tested for significant differences.

Age	**Sampling Universe**	
	Upper	**Lower**
0		169 17, 8
1*	285 a 25, 22	265 a 11, 76
2*	372 a 18, 60	383 a 7, 332
3*	448 a 14, 51	440 a 3, 768
4	488 9, 42	472 2, 811
5	495 11, 15	482 4, 270
6	510 10, 11	480 6, 105
7	516 7, 4	486 15, 22
8	523 2, 2	513 17, 3

Table 13. Age/length key for segment 1. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	**Age**									**Total Number**
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
130										
140										
150										
160										
170										
180										
190										
200										
210										
220										
230										
240										
250										
260										
270										
280										
290										
300										
310										
320										
330										
340										
350										
360										
370										
380										
390										
400										
410										
420										
430										
440						100				**1**
450										
460										
470										
480										
490							100			**1**
500										
510										
520										
Total Number						**1**	**1**			

Table 14. Age/length key for segment 2. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	Age 0	1	2	3	4	5	6	7	8	Total Number
130										
140										
150										
160										
170										
180										
190										
200										
210										
220										
230										
240										
250										
260										
270										
280										
290										
300										
310										
320		100.0								**1**
330										
340										
350				100.0						**1**
360										
370		100.0								**1**
380										
390			50	50.0						**2**
400			42.9	42.9	14.2					**7**
410				100.0						**4**
420			66.7	33.3						**3**
430				50.0	50.0					**4**
440			33.3	66.7						**3**
450				50.0		50.0				**2**
460				50.0		50.0				**2**
470				25.0	50.0		25.0			**4**
480				50.0		50.0				**2**
490			28.7	28.7	14.2	14.2	14.2			**7**
500				20.0	20.0	30.0	20.0	10.0		**10**
510				27.3	36.3	18.1	9.1	9.1		**11**
520					50	16.7		16.7	16.7	**6**
Total Number		**2**	**9**	**25**	**15**	**10**	**5**	**3**	**1**	

Table 15. Age/length key for segment 3. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	Age 0	1	2	3	4	5	6	7	8	Total Number
130										
140										
150										
160										
170										
180										
190										
200										
210										
220										
230		100.0								**1**
240										
250										
260										
270			100.0							**1**
280										
290		50.0	50.0							**2**
300										
310										
320										
330										
340										
350			100.0							**2**
360				100.0						**1**
370			100.0							**1**
380			100.0							**2**
390			100.0							**1**
400			100.0							**1**
410			100.0							**1**
420			33.3	66.7						**3**
430			60.0	20.0	20.0					**5**
440			33.3	33.3	33.3					**3**
450			33.3		33.3	33.3				**3**
460				33.3	66.7					**3**
470			25.0	25.0	50.0					**4**
480			20.0		60.0	20.0				**5**
490					100.0					**1**
500							100.0			**1**
510					62.5	12.5	12.5	12.5		**8**
520				40.0	40.0				20.0	**5**
Total Number		**2**	**18**	**9**	**18**	**3**	**2**	**1**	**1**	

Table 16. Age/length key for segment 4. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	Age 0	1	2	3	4	5	6	7	8	Total Number
130										
140										
150										
160										
170										
180										
190		100.0								**1**
200		100.0								**2**
210		100.0								**1**
220		50.0	50.0							**2**
230		50.0	50.0							**2**
240		100.0								**1**
250			100.0							**3**
260		33.3	66.7							**3**
270		33.3	66.7							**3**
280		40.0	60.0							**5**
290										
300			100.0							**2**
310				100.0						**2**
320		50.0	50.0							**2**
330		50.0	50.0							**2**
340		60.0	40.0							**5**
350										
360		50.0	50.0							**2**
370		50.0	50.0							**2**
380			75.0	25.0						**4**
390			50.0	50.0						**2**
400			100.0							**2**
410			100.0							**1**
420				50.0	50.0					**2**
430			100.0							**3**
440			66.7	33.3						**3**
450										
460			33.3	66.7						**3**
470				60.0	40.0					**5**
480				100.0						**4**
490				50.0	50.0					**2**
500					75.0	25.0				**4**
510				100.0						**1**
520					20.0		80.0			**5**
Total Number		**18**	**33**	**17**	**8**	**1**	**4**			

Table 17. Age/length key for segments 5/6. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	Age 0	1	2	3	4	5	6	7	8	Total Number
130										
140										
150										
160										
170										
180										
190										
200										
210										
220										
230										
240										
250										
260										
270										
280										
290										
300										
310										
320										
330										
340										
350										
360										
370										
380										
390										
400										
410										
420										
430										
440										
450										
460										
470										
480										
490										
500										
510										
520										
Total Number										

Table 18. Age/length key for segment 7. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	**Age**									**Total Number**
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
130										
140										
150										
160										
170										
180										
190										
200										
210										
220										
230										
240										
250										
260										
270										
280										
290										
300										
310										
320										
330										
340										
350										
360										
370										
380										
390										
400										
410										
420										
430										
440			100.0							**1**
450										
460					50.0		50.0			**4**
470				100.0						**2**
480				30.0	40.0	20.0	10.0			**10**
490				18.1	27.3	54.5				**11**
500				25.0	40.0	30.0	5.0			**20**
510				10.0	40.0	40.0	10.0			**10**
520					66.7	25.0	8.3			**12**
Total Number			**1**	**13**	**29**	**23**	**4**			

Table 19. Age/length key for segment 8. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	Age 0	1	2	3	4	5	6	7	8	Total Number
130										
140										
150										
160										
170										
180										
190										
200										
210										
220										
230										
240										
250										
260										
270										
280										
290										
300										
310		100.0								**1**
320		100.0								**2**
330										
340			100.0							**1**
350										
360										
370										
380				100.0						**1**
390										
400				100.0						**2**
410			100.0							**2**
420										
430				85.7	14.3					**7**
440			50.0	25.0	25.0					**4**
450				60.0	20.0	20.0				**5**
460			12.5	50.0	37.5					**8**
470				66.7	20.0	13.3				**15**
480				62.5	31.25	6.25				**16**
490				35.0	40.0	15.0	5.0	5.0		**20**
500				26.3	73.7					**19**
510				40.9	40.9	18.2				**22**
520				36.8	36.8	15.8	10.5			**19**
Total Number		**3**	**6**	**65**	**52**	**14**	**3**	**1**		

Table 20. Age/length key for segment 9. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	**Age**									**Total Number**
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
130										
140										
150										
160	100.0									**1**
170										
180		100.0								**1**
190		100.0								**2**
200		100.0								**1**
210										
220		66.7	33.3							**3**
230										
240										
250										
260										
270		100.0								**1**
280		50.0	50.0							**2**
290										
300			66.7	33.3						**3**
310		25.0	25.0	50.0						**4**
320		10.0	70.0	20.0						**10**
330			71.4	21.4	7.2					**14**
340			75.0	12.5	12.5					**8**
350		16.7	16.7	66.7						**6**
360			37.5	62.5						**8**
370			37.5	62.5						**8**
380			33.3	55.6	11.1					**9**
390			15.4	61.5	23.1					**13**
400				57.1	38.1	4.8				**21**
410			6.4	48.4	32.3	9.7				**31**
420			9.5	61.9	23.8	4.8				**21**
430			5.9	41.2	35.3	17.7				**34**
440			5.9	38.2	50	5.9				**34**
450			2.6	30.8	48.7	17.9				**34**
460			4.6	29.6	47.7	9.1	9.1			**39**
470				17.4	58.7	17.4	6.5			**44**
480				21.7	58.7	8.7	8.7	2.2		**46**
490			2.4	28.5	50.0	19.1				**42**
500			3.2	21.3	50.8	9.8	11.5	3.2		**61**
510				13.4	44.4	34.9	4.8	2.5		**43**
520			2.0	18.0	58.0	16.0	4.0	2.0		**50**
Total Number	**1**	**11**	**55**	**186**	**252**	**73**	**23**	**5**		

Table 21. Age/length key for segment 10. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	Age 0	1	2	3	4	5	6	7	8	Total Number
130	100.0									**1**
140	100.0									**1**
150										
160										
170										
180										
190										
200										
210		100.0								**2**
220		100.0								**1**
230		50.0	50.0							**2**
240		50.0	50.0							**2**
250		33.3	66.7							**3**
260		25.0	75.0							**4**
270			100.0							**2**
280		50.0	50.0							**4**
290		25.0	75.0							**4**
300			100.0							**2**
310			83.3	16.7						**6**
320		14.3	42.8	42.8						**7**
330			66.7	33.3						**6**
340				50.0	50.0					**2**
350			44.5	33.3	22.2					**9**
360			12.5	75.0	12.5					**8**
370			20.0	60.0	20.0					**5**
380			16.7	33.3	50.0					**6**
390			7.7	61.5	30.8					**13**
400			20.0	26.7	40.0	6.7	6.7			**15**
410			10.0	40.0	40.0	10.0				**10**
420			5.2	47.4	26.3	5.3	15.8			**19**
430			13.6	27.3	40.9	13.6	4.6			**22**
440			4.8	23.8	47.6	23.8				**21**
450				27.8	66.7	5.6				**18**
460			15.8	21.0	26.2	31.5	5.5			**19**
470			5.6	22.2	72.2					**18**
480				15.8	47.4	36.8				**19**
490				42.9	35.7	10.7	10.7			**28**
500				13.0	56.5	8.7	17.4	4.3		**23**
510				23.1	53.9	15.4	7.7			**26**
520				23.5	23.5	35.3	5.8	11.8		**17**
Total Number	**2**	**11**	**49**	**98**	**126**	**40**	**16**	**3**		

Table 22. Age/length key for segment 11. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	Age 0	1	2	3	4	5	6	7	8	Total Number
130										
140										
150										
160										
170										
180										
190										
200		100.0								**1**
210										
220										
230										
240										
250										
260										
270										
280										
290										
300										
310			100.0							**1**
320				100.0						**1**
330										
340										
350		50.0	50.0							**2**
360		100.0								**1**
370										
380										
390				100.0						**1**
400			33.3	33.3	33.3					**3**
410				66.7	33.3					**3**
420										
430			33.3	66.7						**3**
440				100.0						**2**
450					100.0					**1**
460				25.0	50.0	25.0				**4**
470					100.0					**1**
480				50.0	50.0					**2**
490				50.0	50.0					**2**
500					100.0					**2**
510				60.0		20.0	20.0			**5**
520				42.9		42.9	14.2			**7**
Total Number		**3**	**4**	**18**	**10**	**5**	**2**			

Table 23. Age/length key for segment 13. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	Age 0	1	2	3	4	5	6	7	8	Total Number
130										
140										
150	100.0									**1**
160	100.0									**1**
170										
180										
190	66.7	33.3								**3**
200	33.3	66.7								**3**
210		100.0								**1**
220		100.0								**2**
230		66.7	33.3							**3**
240		80.0	20.0							**5**
250		66.7	16.7	16.7						**6**
260			83.3	16.7						**6**
270		40.0	40.0	20.0						**5**
280		33.3	66.7							**3**
290										
300			100.0							**3**
310			20.0	80.0						**5**
320			25.0	50.0	25.0					**4**
330			60.0	40.0						**5**
340		11.1	33.3	33.3	22.2					**9**
350			37.50	56.3	6.3					**16**
360			21.0	57.9	21.0					**19**
370			33.3	66.7						**18**
380			29.4	41.2	17.6	5.9	5.9			**17**
390			35.3	47.1	17.7					**17**
400			25.0	55.0	20.0					**20**
410			14.8	55.6	14.8	11.1	3.7			**27**
420			25.0	34.4	31.3	6.3	3.1			**32**
430			13.3	36.7	33.3	6.7	6.7	3.3		**30**
440			12.1	45.5	27.3	12.1		3.0		**33**
450			12.5	15.6	65.6	3.1	3.1			**32**
460			6.4	31.9	29.8	23.4	8.5			**47**
470			8.1	24.3	56.8	8.1	2.7			**37**
480			5.9	41.2	32.4	11.8	8.9			**34**
490			2.9	20.6	35.3	29.4	8.9		2.9	**34**
500			2.6	25.6	48.7	17.9	2.6	2.6		**39**
510			3.0	27.3	36.4	24.2	6.1		3.0	**33**
520			5.1	17.9	64.1	7.7	5.1			**39**
Total Number	**5**	**20**	**92**	**200**	**186**	**59**	**22**	**3**	**2**	

Table 24. Age/length key for segment 14. Numbers in the boxes represent the probability that a known length individual is a certain age based on aging data from each segment.

Length Category	**Age**									**Total Number**
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
130										
140										
150										
160										
170										
180										
190		100.0								**1**
200		100.0								**2**
210			100.0							**1**
220		100.0								**1**
230		50.0	50.0							**2**
240		50.0	50.0							**2**
250		66.7	33.3							**6**
260		57.2	42.8							**7**
270		20.0	80.0							**5**
280		75.0	25.0							**4**
290		33.3	50.0	16.7						**6**
300		25.0	50.0	25.0						**4**
310		16.7	33.3	33.3	16.7					**6**
320		20.0	40.0	20.0	20.0					**5**
330		25.0	25.0	50.0						**8**
340			33.3	22.2	44.4					**9**
350		15.4	30.8	38.5		15.4				**13**
360		5.3	21.1	63.2	10.5					**19**
370			37.5	50.0	6.3	6.3				**16**
380			33.3	25.0	41.6					**12**
390			7.1	57.1	21.4	7.1		7.1		**14**
400			45.5	48.5		6.1				**33**
410			24.0	44.0	24.0	4.0	4.0			**25**
420			27.8	44.4	22.2	2.8	2.8			**36**
430			25.0	35.0	17.5	7.5	12.5	2.5		**40**
440			22.9	31.4	22.9	11.4	11.4			**35**
450			25.0	21.4	42.9	7.1		3.6		**28**
460			9.8	31.7	34.2	12.2	9.8	2.4		**41**
470			11.9	30.9	38.1	11.9	7.1			**42**
480			8.1	27.0	40.5	10.8	10.8	2.7		**37**
490			7.5	12.5	35.0	25.0	12.50	7.5		**40**
500			5.9	41.2	44.1	2.9		5.9		**34**
510			17.2	10.3	44.8	13.8	13.8			**29**
520			2.8	25.0	30.6	27.8	11.1		2.8	**36**
Total Number		**28**	**125**	**188**	**156**	**56**	**35**	**10**	**1**	

Discussion

Shovelnose sturgeon grow rapidly during their first two years, but growth declines substantially thereafter (Tables 4 – 7 and Figures 13 – 18). This pattern of growth was evident in all four years of sampling; however, differences in the total growth varied between segments and years. Specific comparisons of mean length-at-capture for age-1, age-2 and age-3 fish were very similar during the first two years of sampling (Table 8 and 9). Differences in growth were observed for all three age classes in 2005 and for two age classes in 2006 (Table 10 and 11). These differences followed no specific pattern and were hard to interpret on a spatial scale. Upper and lower universe comparisons revealed no significant differences in mean length-at-capture (Table 12), further supporting this claim.

Very few fin rays have been collected for shovelnose sturgeon under 350 mm (N = 281) in length (Table 3). Mean back-calculated fork length-at-last annulus help to better understand growth patterns in these hard to obtain younger fish. Back-calculated lengths that were applied to an age-length key will serve as a good predictor for shovelnose sturgeon age (Tables 13 – 24).

There were very few differences in mean Wr between segments in 2003, 2004 and 2005 (Appendix A – C). Mean Wr of age-1 shovelnose sturgeon were similar among segments in 2006; however, differences between segments were observed for age-2 and age-3 fish (Appendix D). Similar to growth patterns, differences in mean Wr appear to occur in random fashion and are probably related to temporal differences in abiotic and biotic factors. The overall trend in mean Wr appears to be that condition decreases slightly as fish get older; however, variation was observed on a yearly basis.

Previous studies have shown that the complexity of a large river system may induce large variation in growth patterns (Pierce et al. 2003). Pierce et al. (2003) found that length at age-1 for shovelnose sturgeon was significantly different among years; however, this pattern varied across spatial groupings. The authors concluded that these discrepancies are probably a function of local variation in weather, habitat conditions and resource availability. For this study, it became apparent that growth for age 1-3 shovelnose sturgeon varied between years for each of the segments when back-calculated fork length-at-last annulus calculations were assigned into a year class (Appendix G – J). These results will allow researchers to determine how various factors (i.e., flooding, discharge, tributary inputs, etc.) affect growth on an annual basis.

This study had several limitations that inhibited the overall success. Stringent guidelines were established a priori based on previous research and river experience. A 530-mm maximum size restraint on shovelnose sturgeon was imposed due to the known variability in using fin rays as an aging structure. The Population Assessment Team chose 530-mm because this is the size where shovelnose sturgeon become adults and theoretically, growth begins to slow (Pflieger 1997). Many studies have documented large variation while aging adult sturgeon; however, there has been no known validation studies conducted using any of the various aging structures (Rien et al. 1994; Morrow et al. 1998; Hurley et al. 2004; Whiteman et al. 2004).

Our data indicates that the 530-mm maximum size restraint affected many age-4 and older fish (Appendix F). Due to the variation observed in growth on the Missouri River, this analysis did not include comparisons from fish that were older than age-3. In addition, age-1 and age-2 fish were caught in much lower abundance, indicating that these fish may not be fully recruited to our sampling gears. Therefore, samples from age-1 and age-2 fish may not be representative of the entire population.

Collection procedure also may have confounded results. Early in this project, agencies collected shovelnose sturgeon fin rays when sturgeon are suspect to be laying down their current year's annuli. This procedure changed for segments 5-14 prior to the 2005 sampling season. Crews from these segments collected shovelnose sturgeon fin rays during the late fall/early spring seasons, which coincided with winter gill netting efforts. However, gill netting is not incorporated in the standard sampling regime for segments 1-4; therefore, fin rays continue to be collected during the summer months and early fall. The process of removing shovelnose sturgeon fin rays has also changed since the beginning of the project. Originally, fin ray removal consisted of cutting the ray as close to the base of the fin as possible without making an incision into the body. Recent research indicated that age estimates were more accurate on fin rays that were sectioned as close to the articulating process (i.e., "knuckle") of the structure as possible (Koch et al. *In press*). Therefore, agencies began including the articulating process on each sample in 2005.

Although there have been constraints that have limited the scope of this project, we were still able to gain valuable information about growth rates of shovelnose sturgeon. While we were constrained to the number of age-classes that we could examine due to the 530-mm maximum size limit, it appears that recruitment of shovelnose sturgeon is fairly consistent in the channelized Missouri River. There were fewer shovelnose sturgeon collected in the unchannelized segments which may be a function of lower shovelnose sturgeon densities, sampling difficulties or sampling regime. Previously, it was believed that growth was slower in segments located in the upper sampling universe due to colder temperatures and a shorter growing season. This study indicated that factors other than spatial differences have a larger influence in growth patterns for age-1-3 shovelnose sturgeon.

Management Implications/Future Recommendations

The Missouri River is a complex system that confounds standard fish management practices. Typically, large river work is labor intensive and is difficult to sample specific sites due to fish movement in and out of study areas. This study encompassed the entire riverine portion of the Missouri River over several years, thereby effectively allowing managers to observe population dynamics of shovelnose sturgeon on a broad spatial scale. Continued age and growth analysis will allow managers to monitor the health of shovelnose sturgeon and relate this condition to habitat improvements, flow modifications or natural environmental events. In order to further understand population dynamics of shovelnose sturgeon in the Missouri River, we recommend removing the maximum size restraint of 530-mm and continue collecting 10 fin rays per 10-mm length classes for each segment. A full range of shovelnose sturgeon sizes will allow researches to create predictive growth models and to estimate age-specific mortality rates. Although research has shown that there is an increase in variability with fin ray sections as age estimates increase, we feel that the additional information gained will far out-weigh the potential setbacks of reader error. Standardization of fin ray collection times and preparation techniques will also help to reduce variability in age estimates.

Acknowledgments

Funding for this project was provided by the United State Army Corps of Engineers, Omaha District. Lab, office and storage space was provided by Nebraska Game and Parks Commission. Project Supervisors: Gerald Mestl (NGPC) and Mark Drobish (USACE). Collecting Agencies: Montana Fish, Wildlife and Parks, USFWS Missouri River FWMAO (Bismarck, ND), USFWS Great Plains FWMOA (Pierre, SD), South Dakota Game, Fish and Parks, Missouri Department of Conservation, USFWS Fishery Resource Office (Columbia, MO). NGPC Staff: Bill Garvey, Josh Wilhelm, Jim Brannen, Blake Smith, Luke Kowalewski, Ryan Ruskamp, and Travis Kueter.

Principal Investigators

Kirk Steffensen
Fisheries Biologist II
Nebraska Game and Parks Commission
2200 North 33rd Street
Lincoln, NE 68503
Phone Number: 402.471.1514
Fax: 402.471.5528
E-mail: kirk.steffensen@ngpc.ne.gov

Marty Hamel
Fisheries Biologist I
Nebraska Game and Parks Commission
2200 North 33rd Street
Lincoln, NE 68503
Phone Number: 402.471.1514
Fax: 402.471.5528
E-mail: marty.hamel@ngpc.ne.gov

References

Bailey, R. M. and F. B. Cross. 1954. River sturgeons of American genus *Scaphirhynchus*: characters, distribution, and synonymy. Papers of the Michigan Academy of Science, Arts and Letters 39:169-209.

Collins, M. R. and T.I.J. Smith. 1996. Sturgeon fin ray removal is nondeleterious. North American Journal of Fisheries Management 16:939-941.

Drobish, M.R. (editor). 2007. Missouri River Standard Operating Procedures for Sampling and Data Collection, Volume 1.2. U.S. Army Corps of Engineers, Omaha District, Yankton, SD.

Hurley, K.L., R.J. Sheehan, and R.C. Heidinger. 2004. Accuracy and precision of age estimates for pallid sturgeon from pectoral fin rays. North American Journal of Fisheries Management 24:715-718.

Isley, J. J. and T. B. Grabowski. 2007. Age and Growth. Pages 187-228 *in* C. S. Guy and M. L. Brown, editors. Analysis and Interpretation of Freshwater Fisheries Data. American Fisheries Society, Bethesda, Maryland.

Koch, J.D., and M.C. Quist. 2007. A technique for preparing fin rays and spines for age and growth analysis. North American Journal of Fisheries Management 27:782-784.

Koch, J.D., W.J. Schreck, and M.C. Quist. *In press*. Standardized removal and sectioning locations for shovelnose sturgeon fin rays. Fisheries Management and Ecology.

Lee, D. S., C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister and J. R. Stauffer. 1980. Atlas of North American freshwater fishes. North Carolina Museum of Natural History, Raleigh.

Morrow, J.V., Jr., J.P. Kirk, K. J. Killgore, and S.G. George. 1998. Age, growth, and mortality of shovelnose sturgeon in the lower Mississippi River. North American Journal of Fisheries Management 18:725-730.

Pierce, C.L, C.S. Guy, P.J. Braaten, and M.A. Pegg. 2003. Fish growth, mortality, recruitment, condition, and size structure. Volume 4. Population structure and habitat use of benthic fishes along the Missouri River and lower Yellowstone rivers. U.S. Geological Survey, Cooperative Research Units, Iowa State University, Science Hall II, Ames, Iowa 50011.

Pflieger W.L. 1997. The Fishes of Missouri. Jefferson City, MO: Missouri Department of Conservation.

Quist, M. C., C. S. Guy, and P. Braaten. 1998. Standard weight (Ws) equation and length categories for shovelnose sturgeon. North American Journal of Fisheries Management 18:992-997.

Rien, T.A., and R.C. Beamesderfer. 1994. Accuracy and precision of white sturgeon age estimates from pectoral fin rays. Transactions of the American Fisheries Society 123:255-265.

U.S. Fish and Wildlife Service. 1993. Pallid Sturgeon Recovery Plan. U.S. Fish and Wildlife Service, Bismarck, North Dakota. 55pp.

Whiteman, K.W., V.H. Travnichek, M.L. Wildhaber, A. DeLonay, D. Papoulias, and D. Tillett. 2004. Age estimation of shovelnose sturgeon: A cautionary note based on annulus formation in pectoral fin rays. North American Journal of Fisheries Management. 24:731-734.

Appendices

Appendix A. Mean relative weight (Wr) comparisons of shovelnose sturgeon by age between segments for 2003. Numbers below relative weight are (+/-) 95% confidence interval and sample size, respectively. Dashes (-) indicate insufficient data to calculate confidence interval. Asterisks indicate ages tested for significant differences among segments. Segment comparisons were done with a one-way ANOVA. Segments sharing a letter indicate no significant differences while different letters indicate significance differences (Tukey's test, alpha = 0.05). Only age-1, age-2 and age-3 were tested for significant differences.

Age	**Year Class**	**Segment**		
		9	**13**	**14**
0	2003			
1*	2002			
2*	2001	59.8 -- , 1	84.8 -- , 1	
3*	2000	79.7 a 3.2 , 41	89.6 b 4.9 , 27	86.9 b 4.1 , 29
4	1999	89.5 2.4 , 72	86.7 3.8, 13	83.8 3.7 , 25
5	1998	87.6 3.8 , 22	86.2 9.4 , 4	92.9 12.5 , 5
6	1997	84.9 7.2 , 4		
7	1996			
8	1995			

Appendix B. Mean relative weight (Wr) comparisons of shovelnose sturgeon by age between segments for 2004. Numbers below relative weight are (+/-) 95% confidence interval and sample size, respectively. Dashes (-) indicate insufficient data to calculate confidence interval. Asterisks indicate ages tested for significant differences among segments. Segment comparisons were done with a one-way ANOVA. Segments sharing a letter indicate no significant differences while different letters indicate significance differences (Tukey's test, alpha = 0.05). Only age-1, age-2 and age-3 were tested for significant differences.

Age	**Year Class**	**Segment**		
		9	**13**	**14**
0	2004			
1*	2003			
2*	2002		91.7 a 6.6 , 11	86.9 a 4.6 , 9
3*	2001	85.6 a 1.9 , 44	86.1 a 3.0 , 44	85.6 a 5.2 , 20
4	2000	85.8 2.2 , 63	86.5 3.1 , 37	82.7 4.8 , 15
5	1999	93.9 5.8 , 8	83.8 4.3 , 11	95.9 -- , 1
6	1998		87.5 -- , 1	
7	1997			
8	1996			

Appendix C. Mean relative weight (Wr) comparisons of shovelnose sturgeon by age between segments for 2005. Numbers below relative weight are (+/-) 95% confidence interval and sample size, respectively. Dashes (-) indicate insufficient data to calculate confidence interval. Asterisks indicate ages tested for significant differences among segments. Segment comparisons were done with a one-way ANOVA. Segments sharing a letter indicate no significant differences while different letters indicate significance differences (Tukey's test, alpha = 0.05). Only age-1, age-2 and age-3 were tested for significant differences.

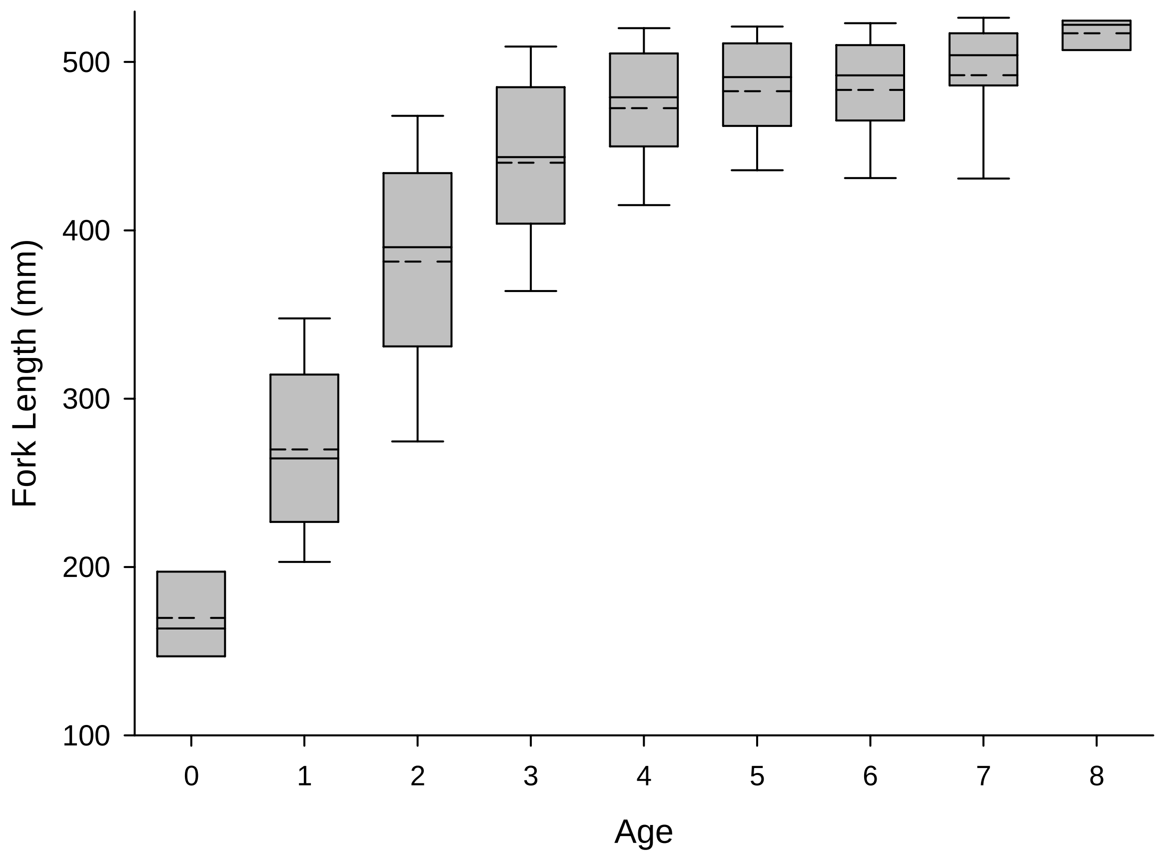
Age	Year Class	Segment							
		4	7	8	9	10	11	13	14
0	2005					132.2 12.1 , 2			
1*	2004	101.9 a 10.6 , 6		80.4 a 18.1 , 3	90.7 a 20.8 , 5	87.6 a 7.2 , 9	93.4 a -- , 1	105.2 a 6.1 , 6	98.8 a 13.0 , 12
2*	2003	94.7 a 7.7 , 8		76.8 a -- , 1	84.0 a 4.5 , 24	83.4 a 2.4 , 35	90.5 a -- , 1	86.1 a 3.3 , 46	87.0 a 2.4 , 74
3*	2002	83.1 a 9.8 , 6	84.2 a 3.1 , 25	85.8 a 3.1 , 33	87.1 a 2.7 , 43	82.6 a 1.8 , 56	102.0 b 6.6 , 6	87.6 a 2.6 , 59	87.3 a 2.8 , 73
4	2001	95.3 -- , 1	84.3 3.0 , 25	83.6 3.9 , 26	86.8 2.5 , 55	83.0 2.0 , 67		88.8 3.1 , 40	86.2 3.7 , 36
5	2000		84.5 3.9 , 17	85.0 8.5 , 7	87.3 2.5 , 16	83.3 3.3 , 19		89.0 4.9 , 8	86.2 3.8 , 9
6	1999	92.6 12.1 , 3	88.0 4.2 , 3	88.7 -- , 1	89.7 6.3 , 6	88.9 4.6 , 5		78.5 22.7 , 2	92.8 21.7 , 2
7	1998				86.7 -- , 1	87.2 -- , 1			
8	1997							103.6 -- , 1	

Appendix D. Mean relative weight (Wr) comparisons of shovelnose sturgeon by age between segments for 2006. Numbers below relative weight are (+/-) 95% confidence interval and sample size, respectively. Dashes (-) indicate insufficient data to calculate confidence interval. Asterisks indicate ages tested for significant differences among segments. Segment comparisons were done with a one-way ANOVA. Segments sharing a letter indicate no significant differences while different letters indicate significance differences (Tukey's test, alpha = 0.05). Only age-1, age-2 and age-3 were tested for significant differences.

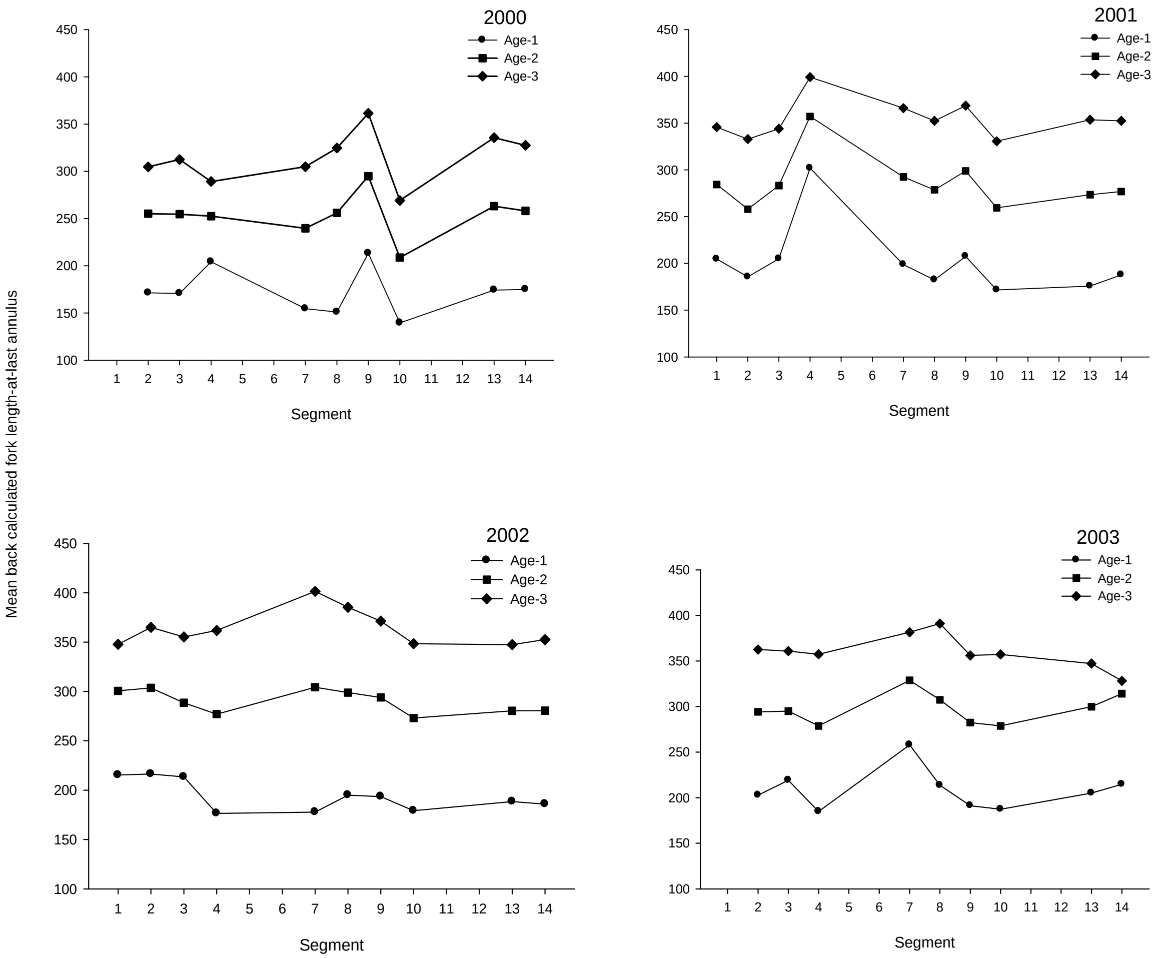
Age	**Year Class**	**Segment**										
		1	**2**	**3**	**4**	**7**	**8**	**9**	**10**	**11**	**13**	**14**
0	2006											
1*	2005		81.6 a 12.8 , 2	91.8 a 6.4 , 2	103.7 a 8.1 , 12			84.1 a 5.7 , 4	92.8 a 5.8 , 2	92.6 a -- , 1	91.0 a 3.9 , 2	92.4 a 9.2 , 5
2*	2004		81.1 a 11.6 , 8	89.6 ab 9.7 , 16	101.9 b 8.4 , 21	76.2 ab -- , 1	84.5 ab 17.2 , 3	84.5 a 3.3 , 27	91.9 ab 8.0 , 13	92.7 ab 4.9 , 3	94.0 ab 9.2 , 10	94.6 ab 6.8 , 17
3*	2003		79.6 a 5.2 , 25	83.4 ab 10.6 , 9	96.6 b 7.0 , 11	83.8 ab -- , 1	85.7 ab 3.2 , 32	88.5 ab 3.2 , 51	90.2 b 3.1 , 40	94.9 b 4.7 , 12	90.0 a 7.4 , 21	92.0 b 4.8 , 29
4	2002	98.3 -- , 1	80.7 9.0 , 14	86.8 4.0 , 18	99.4 13.7 , 6	79.9 2.8 , 4	89.2 3.6 , 26	86.6 2.7 , 54	93.6 2.0 , 56	95.3 4.7 , 10	95.2 5.2 , 22	94.7 3.4 , 48
5	2001	95.2 -- , 1	83.6 10.2 , 10	74.8 4.8 , 3	86.9 -- , 1	78.2 4.4 , 5	86.2 5.4 , 7	88.1 4.5 , 24	95.3 4.8 , 21	98.8 4.8 , 5	100.4 8.4 , 17	99.4 4.7 , 32
6	2000		73.6 16.8 , 5	83.5 3.2 , 2	95.1 -- , 1	78.7 -- , 1	96.4 17.2 , 2	91.7 5.5 , 12	91.2 4.7 , 11	96.5 17.3 , 2	94.6 6.1 , 17	102.0 5.2 , 28
7	1999		89.0 24.8 , 3	92.6 -- , 1			82.5 -- , 1	93.8 7.6 , 4	92.0 19.3 , 2		85.2 0.1 , 2	98.8 6.5 , 9
8	1998		93.7 -- , 1	82.0 -- , 1							100.2 -- , 1	94.0 -- , 1

Appendix E. Mean relative weight (Wr) comparisons of shovelnose sturgeon by age between the upper and lower sampling universe. Numbers below relative weight are (+/-) 95% confidence interval and sample size, respectively. Dashes (-) indicate insufficient data to calculate confidence interval. Asterisks indicate ages tested for significant differences among sampling universes. Sampling universe comparisons were done with a t-test. Sharing a letter indicate no significant differences while different letters indicate significance differences (alpha = 0.05). Only age-1, age-2 and age-3 were tested for significant differences.

Age	**Sampling Universe**	
	Upper	**Lower**
0		132.2 12.1 , 2
1*	100.1 a 5.9 , 22	93.0 a 4.5 , 50
2*	94.0 a 5.2 , 53	86.9 b 1.3 , 277
3*	84.3 a 4.0 , 51	86.9 a 0.8 , 672
4	87.1 4.5 , 40	87.8 0.8 , 694
5	82.9 7.2 , 15	90.3 1.5 , 238
6	82.5 9.5 , 11	94.2 2.4 , 97
7	89.9 17.6 , 4	93.8 4.2 , 20
8	87.8 11.7 , 2	99.3 5.6 , 3



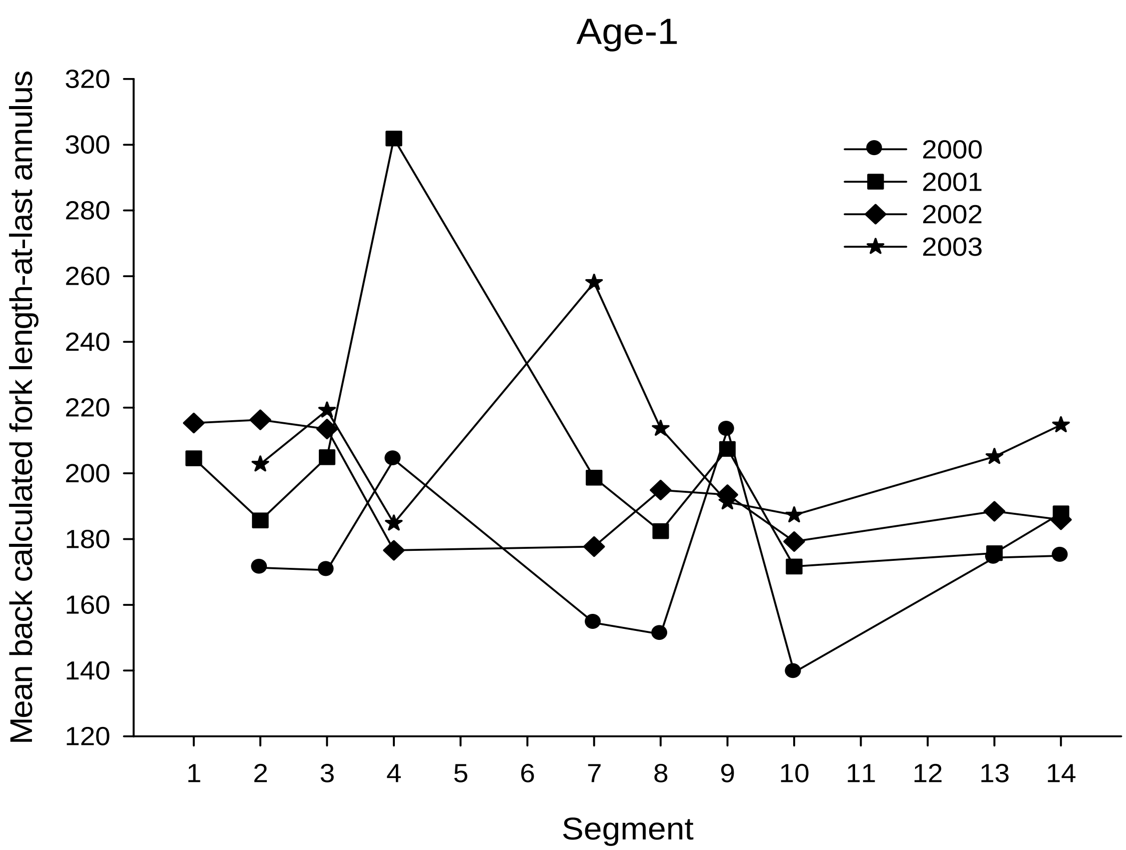
Appendix F. Number of fin rays collected by age class for 2003, 2004, 2005 and 2006 in the Missouri River. Each box plot presents the median (solid line), mean (dashed line), upper and lower quartiles (upper and lower box boundaries) and two standard errors (error bars).



Appendix G. Mean back-calculated fork length-at-last annulus for age-1, age-2 and age-3 shovelnose sturgeon between segments for each year.

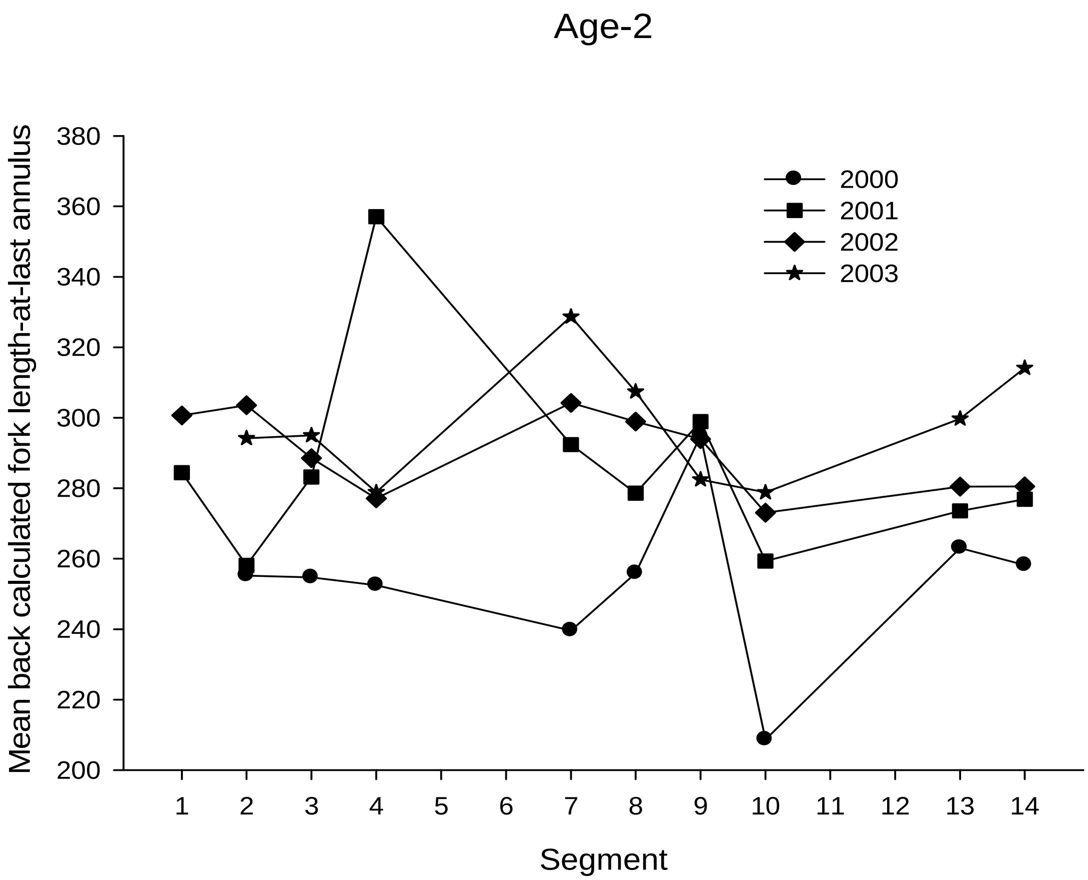
Appendix H. Mean back-calculated fork length-at-last annulus between segments by year class for age-1 shovelnose sturgeon. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (--) indicate insufficient data to calculate confidence interval. Asterisks indicate year class tested for significant differences among segments. Segment comparisons were done with a one-way ANOVA. Segments sharing a letter indicate no significant differences while different letters indicate significant differences (Tukey's test, alpha = 0.10).

Year Class	Segment									
	1	2	3	4	7	8	9	10	13	14
2000		171.2 abc 56, 5	170.5 abc 24, 2	204.2 abc -- , 1	154.5 ac 19, 19	151.0 ac 31, 9	213.3 b 9, 135	139.5 c 21, 30	174.3 a 10, 119	174.9 a 12, 101
2001	204.5 abc -- , 1	185.6 abc 20, 10	204.9 abc 67, 3	301.9 c 32, 2	198.7 abc 22, 30	182.3 abc 18, 33	207.4 c 10, 130	171.7 ab 10, 88	175.7 ab 10, 117	187.8 abc 12, 117
2002	215.3 a -- , 1	216.2 a 23, 15	213.4 a 26, 18	176.5 a 33, 13	177.7 a 25, 16	194.9 a 12, 59	193.5 a 9, 102	179.2 a 10, 117	188.4 a 10, 118	185.9 a 9, 156
2003		202.8 ab 22, 25	219.2 ab 49, 9	184.8 ab 24, 19	258.0 ab -- , 1	213.6 ab 16, 33	191.2 ab 12, 79	187.3 a 13, 76	205.1 ab 12, 95	214.7 b 11, 128



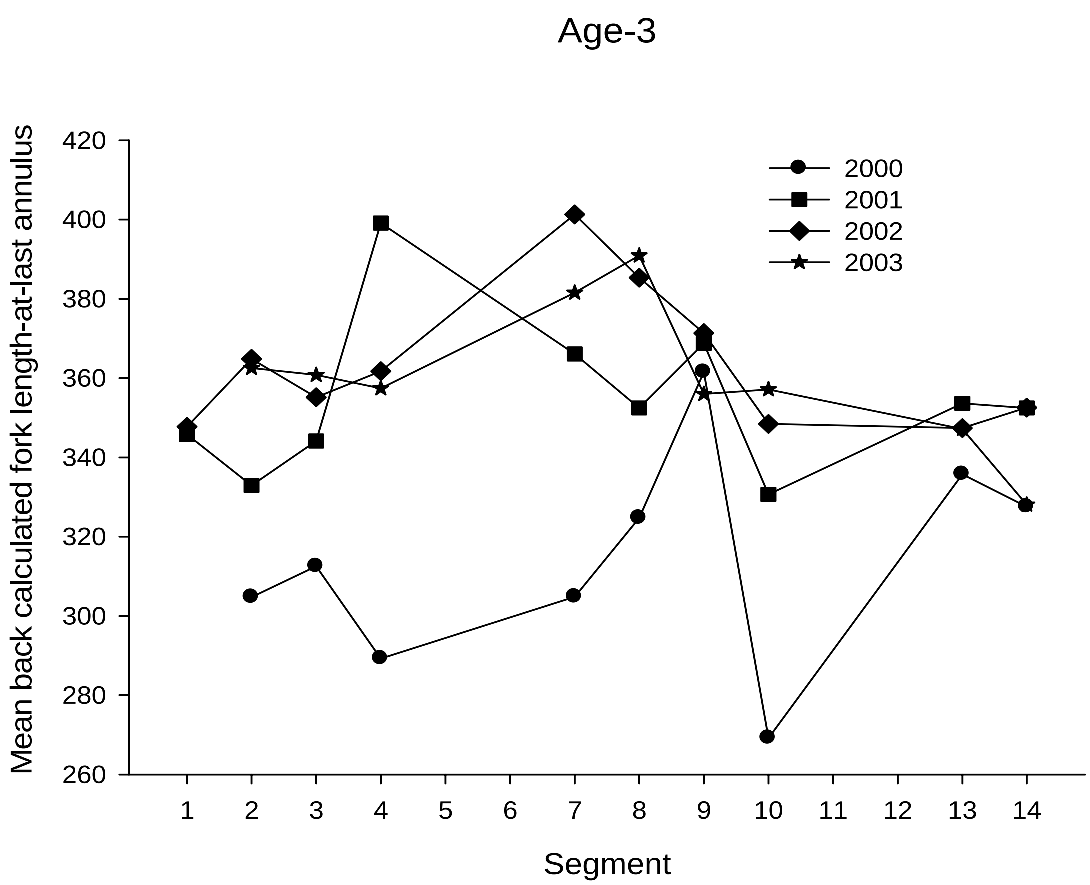
Appendix I. Mean back-calculated fork length-at-last annulus between segments by year class for age-2 shovelnose sturgeon. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (--) indicate insufficient data to calculate confidence interval. Asterisks indicate year class tested for significant differences among segments. Segment comparisons were done with a one-way ANOVA. Segments sharing a letter indicate no significant differences while different letters indicate significant differences (Tukey's test, alpha = 0.10).

Year Class	Segment									
	1	2	3	4	7	8	9	10	13	14
2000		255.2 abc 31, 5	254.7 abc 36, 2	252.5 abc -- , 1	239.6 ac 25, 19	255.9 abc 38, 9	294.9 b 10, 135	208.7 c 20, 30	263.0 a 11, 119	258.2 a 12, 101
2001	284.4 abc -- , 1	258.1 abc 22, 10	283.2 abc 49, 3	357.1 abc 35, 2	292.4 abc 20, 30	278.6 abc 18, 33	298.9 c 10, 130	259.3 ab 10, 88	273.6 ab 10, 117	276.9 ab 12, 117
2002	3007 a -- , 1	303.6 a 20, 15	288.5 a 24, 18	277.1 a 33, 13	304.2 a 28, 16	298.9 a 11, 59	293.9 a 10, 102	273.1 a 11, 117	280.5 a 11, 118	280.5 a 9, 156
2003		294.3 ab 19, 25	295.0 ab 41, 9	278.9 ab 24, 19	328.7 ab -- , 1	307.4 ab 15, 33	282.5 a 13, 79	278.8 a 14, 76	299.8 ab 13, 95	314.2 b 13, 128



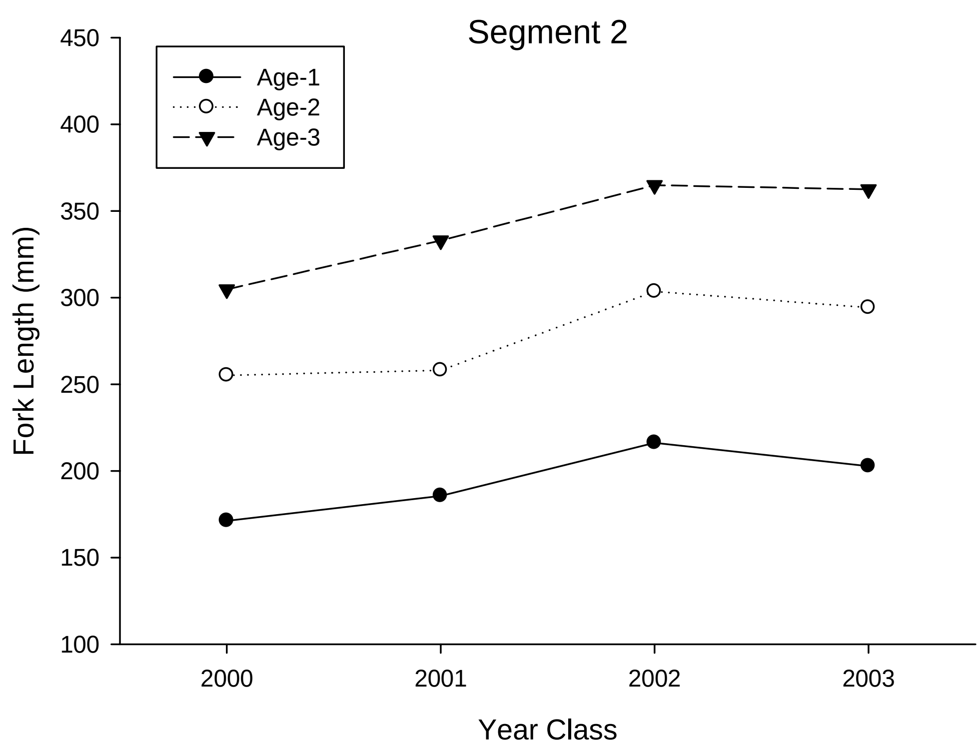
Appendix J. Mean back-calculated fork length-at-last annulus between segments by year class for age-3 shovelnose sturgeon. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (--) indicate insufficient data to calculate confidence interval. Asterisks indicate year class tested for significant differences among segments. Segment comparisons were done with a one-way ANOVA. Segments sharing a letter indicate no significant differences while different letters indicate significant differences (Tukey's test, alpha = 0.10).

Year Class	Segment									
	1	**2**	**3**	**4**	**7**	**8**	**9**	**10**	**13**	**14**
2000		304.7 abc 31, 5	312.5 abc 65, 2	289.2 abc -- , 1	304.8 ac 27, 19	324.7 abc 35, 9	361.5 b 10, 135	269.2 c 19, 30	335.7 a 11, 119	327.5 a 13, 101
2001	345.8 abc -- , 1	332.9 abc 19, 10	344.1 abc 20, 3	399.1 abc 55, 2	366.1 ab 17, 30	352.5 abc 17, 33	368.7 ab 9, 129	330.7 c 10, 88	353.6 abc 10, 114	352.4 abc 13, 117
2002	347.7 abc -- , 1	364.8 abc 17, 15	355.1 abc 20, 18	361.7 abc 29, 13	401.3 a 29, 16	385.3 a 11, 59	371.3 ac 10, 102	348.4 b 11, 117	347.4 b 11, 104	352.5 bc 10, 139
2003		362.5 ab 20, 25	360.8 ab 42, 9	357.4 ab 43, 11	381.6 ab -- , 1	390.9 a 14, 32	356.0 b 13, 55	357.1 ab 16, 40	347.1 b 22, 32	328.0 b 15, 40



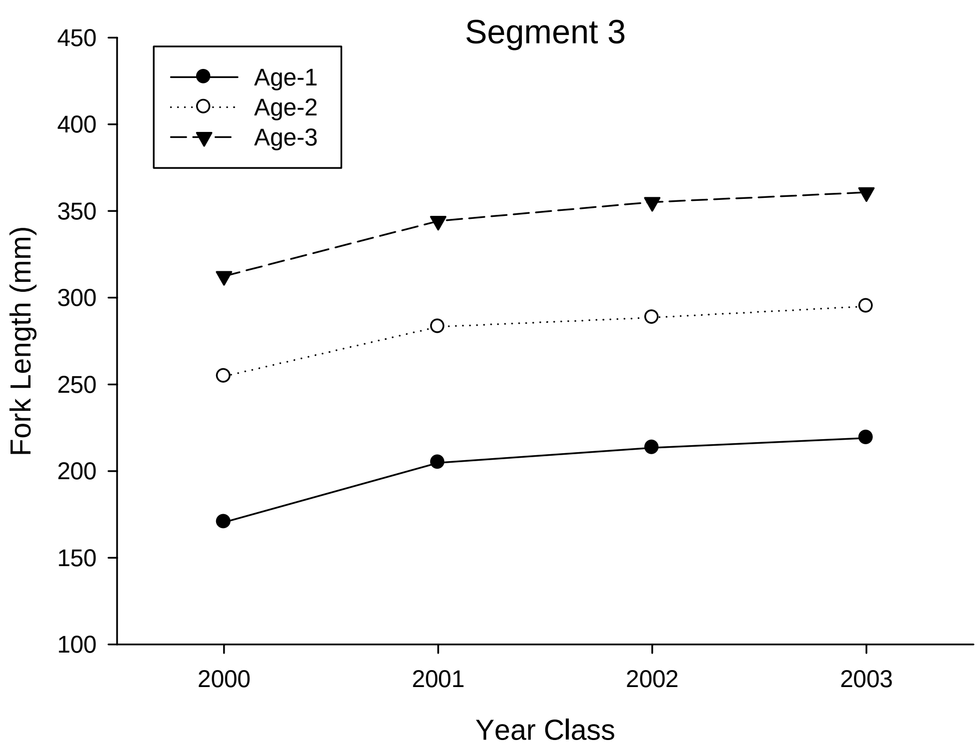
Appendix K. Mean back-calculated fork length-at-last annulus between age groups by year class for segment 2. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (--) indicate insufficient data to calculate confidence interval. Asterisks indicate age groups tested for significant differences among year classes. Year class comparisons were done with a one-way ANOVA. Year classes sharing a letter indicate no significant differences while different letters indicate significant differences (Tukey's test, alpha = 0.10).

Age	Year Class			
	2000	**2001**	**2002**	**2003**
1*	171.2 a 56, 5	185.6 a 20, 10	216.3 a 22, 15	202.7 a 22, 25
2*	255.1 ab 31, 5	258.0 a 22, 10	303.5 b 20, 15	294.1 ab 19, 25
3*	304.7 a 30, 5	332.9 ab 19, 10	364.8 b 16, 15	362.4 b 41, 25



Appendix L. Mean back-calculated fork length-at-last annulus between age groups by year class for segment 3. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (--) indicate insufficient data to calculate confidence interval. Asterisks indicate age groups tested for significant differences among year classes. Year class comparisons were done with a one-way ANOVA. Year classes sharing a letter indicate no significant differences while different letters indicate significant differences (Tukey's test, alpha = 0.10).

Age	**Year Class**			
	2000	**2001**	**2002**	**2003**
1*	170.5 a 24, 2	204.8 a 66, 3	213.4 a 26, 18	219.1 a 48, 9
2*	254.6 a 35, 2	283.1 a 49, 3	288.5 a 23, 18	295.0 a 40, 9
3*	312.4 a 65, 2	344.1 a 20, 3	355.1 a 19, 18	360.7 a 41, 9



Appendix M. Mean back-calculated fork length-at-last annulus between age groups by year class for segment 4. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (--) indicate insufficient data to calculate confidence interval. Asterisks indicate age groups tested for significant differences among year classes. Year class comparisons were done with a one-way ANOVA. Year classes sharing a letter indicate no significant differences while different letters indicate significant differences (Tukey's test, alpha = 0.10).

Age	Year Class			
	2000	**2001**	**2002**	**2003**
1*	204.2 ab -- , 1	301.8 b 31, 2	176.5 a 33, 13	184.7 a 23, 19
2*	252.4 a -- , 1	357.1 a 34, 2	277.1 a 33, 13	278.8 a 23, 19
3*	289.2 a -- , 1	399.1 a 54, 2	361.7 a 28, 13	357.4 a 43, 11

Appendix N. Mean back-calculated fork length-at-last annulus between age groups by year class for segment 7. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (--) indicate insufficient data to calculate confidence interval. Asterisks indicate age groups tested for significant differences among year classes. Year class comparisons were done with a one-way ANOVA. Year classes sharing a letter indicate no significant differences while different letters indicate significant differences (Tukey's test, alpha = 0.10).

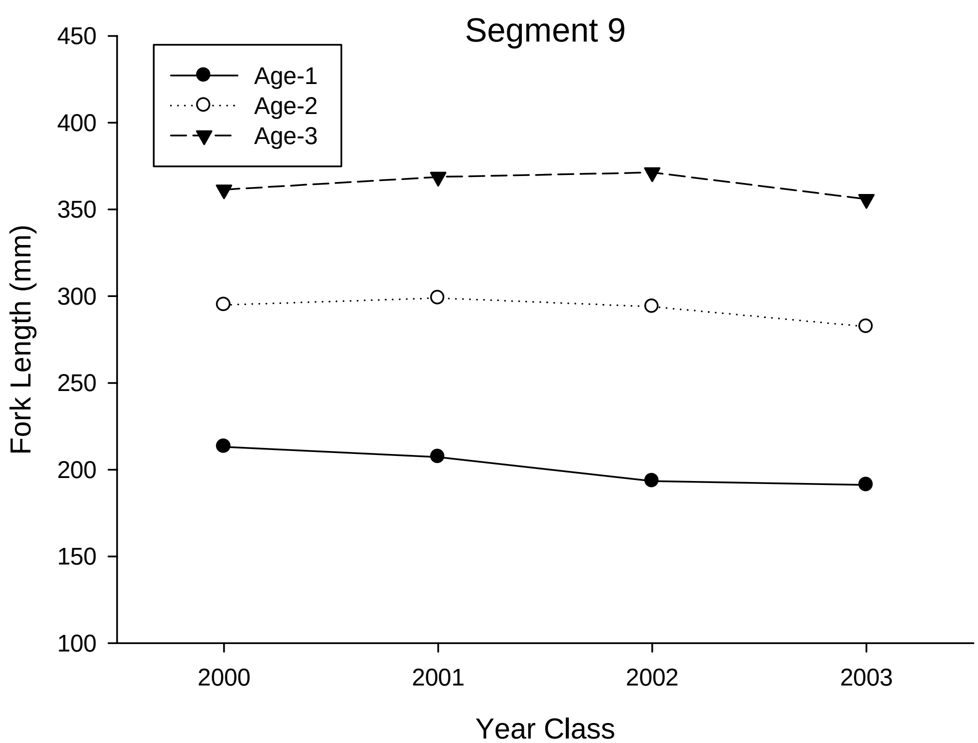
Age	**Year Class**			
	2000	**2001**	**2002**	**2003**
1*	154.4 a 19, 19	198.6 b 22, 30	177.6 ab 24, 16	258.0 ab -- , 1
2*	239.6 a 24, 19	292.4 b 19, 30	304.2 b 27, 16	328.7 ab -- , 1
3*	304.8 a 27, 19	366.0 b 17, 30	401.3 b 28, 16	381.5 ab -- , 1

Appendix O. Mean back-calculated fork length-at-last annulus between age groups by year class for segment 8. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (--) indicate insufficient data to calculate confidence interval. Asterisks indicate age groups tested for significant differences among year classes. Year class comparisons were done with a one-way ANOVA. Year classes sharing a letter indicate no significant differences while different letters indicate significant differences (Tukey's test, alpha = 0.10).

Age	**Year Class**			
	2000	**2001**	**2002**	**2003**
1*	151.0 a 31, 9	182.3 ac 17, 33	194.9 bc 11, 59	213.6 b 16, 33
2*	255.8 a 34, 9	278.6 ac 18, 33	298.9 bc 11, 59	307.4 b 15, 33
3*	324.7 a 34, 9	352.4 a 17, 33	385.3 b 10, 59	390.9 b 13, 32

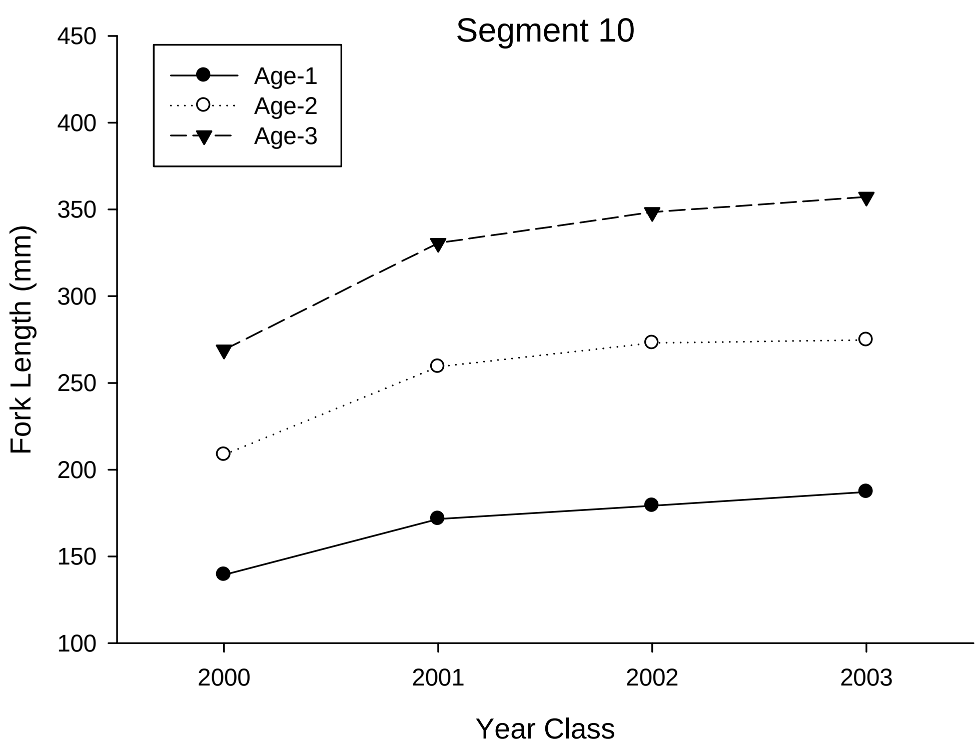
Appendix P. Mean back-calculated fork length-at-last annulus between age groups by year class for segment 9. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (--) indicate insufficient data to calculate confidence interval. Asterisks indicate age groups tested for significant differences among year classes. Year class comparisons were done with a one-way ANOVA. Year classes sharing a letter indicate no significant differences while different letters indicate significant differences (Tukey's test, alpha = 0.10).

Age	Year Class			
	2000	**2001**	**2002**	**2003**
1*	213.2 a 9, 135	207.3 ac 10, 130	193.4 bc 8, 102	191.2 bc 12, 79
2*	294.9 a 9, 135	298.9 a 9, 130	293.9 a 10, 102	282.4 a 12, 79
3*	361.4 a 9, 135	368.7 a 8, 129	371.3 a 10, 102	355.9 a 12, 55



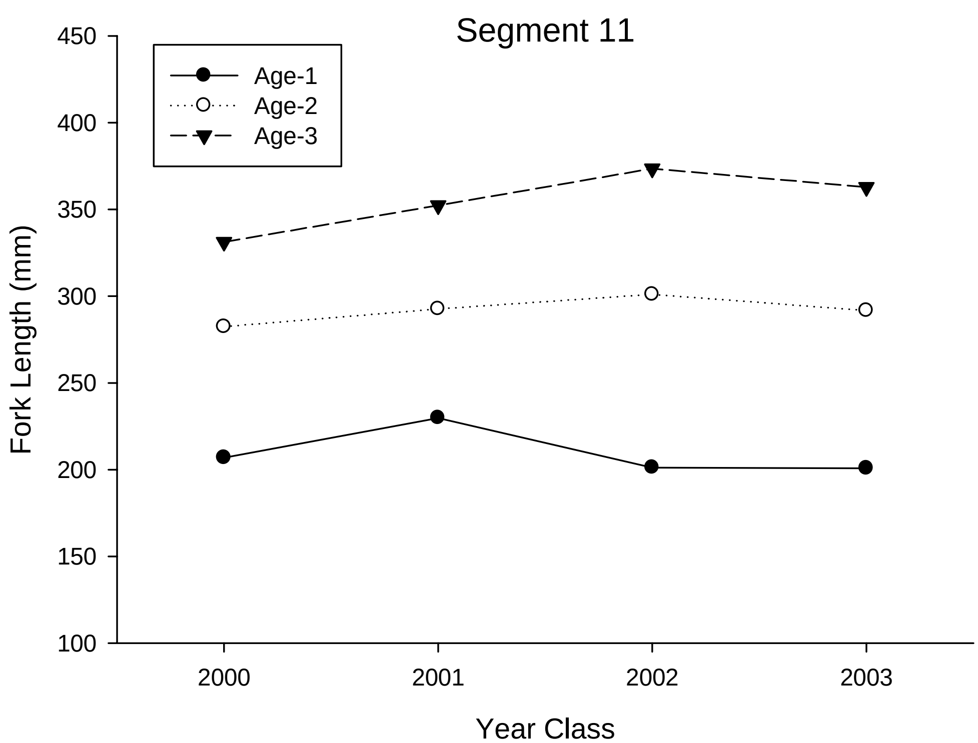
Appendix Q. Mean back-calculated fork length-at-last annulus between age groups by year class for segment 10. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (--) indicate insufficient data to calculate confidence interval. Asterisks indicate age groups tested for significant differences among year classes. Year class comparisons were done with a one-way ANOVA. Year classes sharing a letter indicate no significant differences while different letters indicate significant differences (Tukey's test, alpha = 0.10).

Age	**Year Class**			
	2000	**2001**	**2002**	**2003**
1*	139.4 a 20, 30	171.6 b 9, 88	179.2 b 10, 117	187.2 b 13, 76
2*	208.6 a 20, 30	259.3 b 9, 88	273.0 b 10, 117	274.7 b 13, 76
3*	269.1 a 19, 30	330.6 b 10, 88	348.4 c 10, 117	357.1 c 16, 40



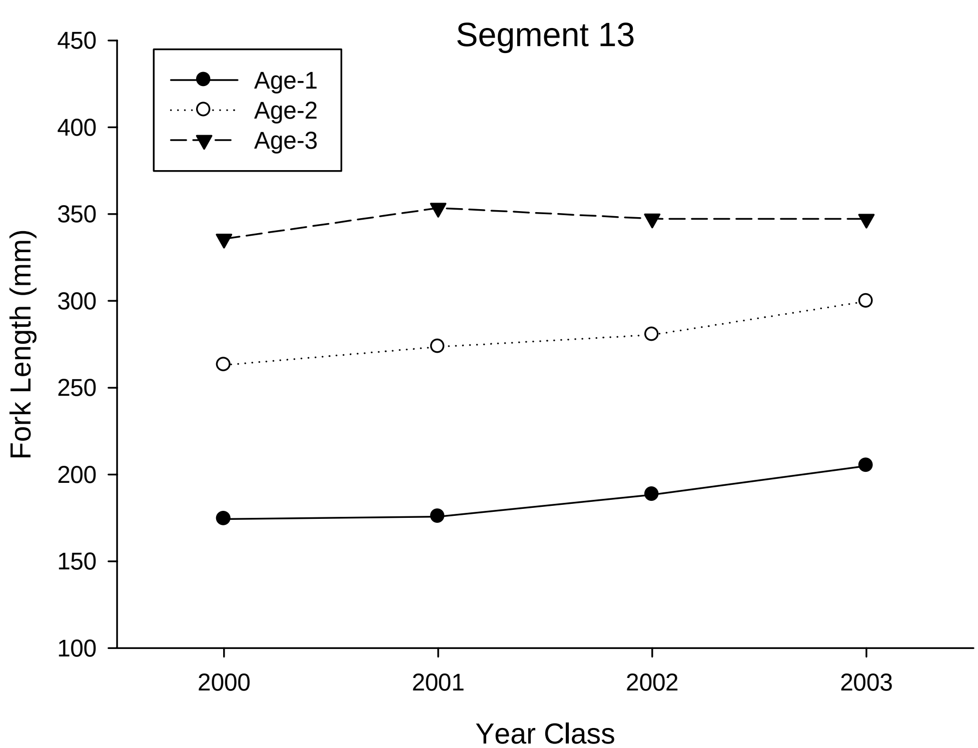
Appendix R. Mean back-calculated fork length-at-last annulus between age groups by year class for segment 11. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (--) indicate insufficient data to calculate confidence interval. Asterisks indicate age groups tested for significant differences among year classes. Year class comparisons were done with a one-way ANOVA. Year classes sharing a letter indicate no significant differences while different letters indicate significant differences (Tukey's test, alpha = 0.10).

Age	**Year Class**			
	2000	**2001**	**2002**	**2003**
1*	206.9 a 108, 2	229.8 a 39, 5	201.2 a 27, 16	200.8 a 25, 13
2*	282.4 a 69, 2	292.5 a 34, 5	301.0 a 28, 16	291.7 a 26, 13
3*	331.1 a 84, 2	352.3 a 32, 5	373.5 a 34, 16	362.8 a 30, 12



Appendix S. Mean back-calculated fork length-at-last annulus between age groups by year class for segment 13. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (--) indicate insufficient data to calculate confidence interval. Asterisks indicate age groups tested for significant differences among year classes. Year class comparisons were done with a one-way ANOVA. Year classes sharing a letter indicate no significant differences while different letters indicate significant differences (Tukey's test, alpha = 0.10).

Age	Year Class			
	2000	**2001**	**2002**	**2003**
1*	174.3 a 9, 119	175.7 a 9, 117	188.4 ac 9, 118	205.0 bc 11, 95
2*	263.0 a 11, 119	273.5 a 9, 117	280.4 a 11, 118	299.7 b 13, 95
3*	335.7 a 10, 119	353.5 a 10, 114	347.3 a 11, 104	347.1 a 21, 32



Appendix T. Mean back-calculated fork length-at-last annulus between age groups by year class for segment 14. Numbers below mean lengths are (+/-) 95% confidence interval and sample size, respectively. Dashes (--) indicate insufficient data to calculate confidence interval. Asterisks indicate age groups tested for significant differences among year classes. Year class comparisons were done with a one-way ANOVA. Year classes sharing a letter indicate no significant differences while different letters indicate significant differences (Tukey's test, alpha = 0.10).

Age	Year Class			
	2000	**2001**	**2002**	**2003**
1*	174.8 a 11, 101	187.8 a 11, 117	185.8 a 9, 156	214.7 b 11, 128
2*	258.1 a 12, 101	276.8 ad 11, 117	280.5 bd 8, 156	314.1 c 12, 128
3*	327.5 a 13, 101	352.4 b 12, 117	352.5 b 9, 139	328.0 ab 14, 40